

AIRBORNE OCEANOGRAPHIC LIDAR SYSTEM  
FINAL REPORT

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prepared by  
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## FOREWORD

This report has been prepared by Avco Everett Research Laboratory, Inc. (AERL) to summarize the results under Contract NAS6-2653, the purpose of which was to prepare the specifications and preliminary design for an Airborne Oceanographic Lidar System (AOL), which is to be installed on a National Aeronautics and Space Administration (NASA), Wallops Flight Center, C-54 research aircraft.

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## SECTION I

### INTRODUCTION

This report has been prepared to summarize the activities under Contract NAS6-2653, which had as its purpose the preparation of the specifications and preliminary design of an AOL system, which is to be constructed for installation and use on a NASA Wallops Flight Center (WFC) C-54 research aircraft. The AOL system is to provide an airborne facility for use by various government agencies to demonstrate the utility and practicality of hardware of this type in the wide area collection of oceanographic data on an operational basis. Being accomplished under the Advanced Applications Flight Experiments (AAFE) Program, the data obtained from system utilization will directly support NASA's EOPAP, SEASAT and ERTS programs in the areas of bathymetry, oil slick detection and identification, and algae detection and mapping.

AOL specification and design activities were performed over the four month period between June and October, 1975. Using a Design Team approach,<sup>(1)</sup> the measurement requirements, which the AOL system was to be configured to meet, were reviewed and refined and system performance requirements identified. In conjunction with the latter, a system concept was developed and refined, from which the system specifications and preliminary design emanated. This report has been structured to be compatible with the flow of program activities and development, e. g. , the system measurement and performance requirements are first presented, followed by a description of the conceptual system approach and the considerations attendant to its development. System performance calculations are then addressed, and lastly, the system specifications and preliminary design are presented and discussed.

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<sup>(1)</sup> The Design Team was comprised of both NASA WFC and AERL personnel, with H. H. Kim of NASA and I. Itzkan of AERL as experiment co-investigators.

## SECTION II

### SYSTEM MEASUREMENT AND PERFORMANCE REQUIREMENTS

#### 1.0 MEASUREMENT REQUIREMENTS

On 22/23 January and 11/12 February 1975, respectively, a laser Hydrography and a Laser Fluorosensor Workshop were held to define, as best as practicable, the Government user measurement requirements for the AOL system. Representatives of sixteen United States and Canadian Government agencies were present. The results of these Workshops were documented,<sup>1,2</sup> distributed to all participants, and formed the basis for the Design Team to jointly establish the type and range of measurement requirements to which the AOL is to be configured to satisfy. The results of the Design Team assessments are summarized in Tables I and II, which contain the basic requirements that the AOL will be configured to meet.

#### 2.0 PERFORMANCE REQUIREMENTS

In parallel with and subsequent to the definition of the basic measuring requirements, the Design Team addressed the more significant system performance requirements expected of the AOL. These are summarized in Tables III through V. These data, in conjunction with the measurement requirements, previously discussed, provided the baseline for the development of the detailed AOL system specifications and preliminary design.

#### 3.0 DESIGN CONSIDERATIONS AND CONSTRAINTS

The AOL system is to be installed either on NASA Wallops Flight Center C54-G aircraft N427NA or N438NA. One of the major constraints imposed on the design of the system by the Design Team is that it be configured in a manner which would minimize the requirements for aircraft modifications attendant with its installation and use. Other general constraints included that the system be configured to allow extreme flexibility for interchanging laser transmitters and that all elements requiring adjustment or removal/replacement during system use be readily accessible.

TABLE I  
AOL MEASUREMENT REQUIREMENTS SUMMARY  
BATHYMETRY

Application	Coastal water charting; fish school detection and track
Area Coverage	One data point per 20 m <sup>2</sup> maximum, $\pm 5$ deg from nadir; also capability to $\pm 15$ deg from nadir
Maximum Measurement Depth	6 m with $\alpha = 2 \text{ m}^{-1}$ required, $\alpha = 3 \text{ m}^{-1}$ desired; 10 m with $\alpha = 1 \text{ m}^{-1}$
Minimum Measurement Depth	0.6 m
Vertical Measurement Accuracy	$\pm 0.3 \text{ m}$
Horizontal Measurement Accuracy	$\pm 1.07 \text{ m}^{(1)}$
Sea State Conditions	Measurement required
Platform Characteristics	
Altitude	152 m to 609 m
Velocity	278 km/hr
Background Conditions	Day and night operation required
Ground Truth Data	Required via wide angle footprint camera and autotape
Attitude Stabilization	Not required

<sup>(1)</sup> AOL system contribution, at an aircraft altitude of 609 m, towards a stated 5 m RMS reading accuracy requirement. The aircraft positional and attitude readout RMS equivalency, at 609 m, is estimated to be  $\pm 4.93 \text{ m}$ .

TABLE II  
AOL MEASUREMENT REQUIREMENTS SUMMARY  
FLUOROSENSING

Application	Oil detection and identification; mineral resource survey; crop growth and disease identification, air sea rescue; ocean temperature, salinity and current determination; identification of hazardous materials and pollutants; algae detection and measurement
Data Rate	$\leq 100$ per sec
Excitation Spectral Range	3371 Å to 6600 Å, variable
Emission Spectral Range	3500 Å to 8000 Å
Emission Spectral Resolution	100 Å channels over spectral range
Emission Temporal Resolution	8 nsec to 50 nsec, variable
Platform Characteristics	
Altitude	152 m
Velocity	278 km/hr
Background Conditions	Day and night operation required
Ground Truth Data	Required via wide angle footprint camera and autotape

TABLE III  
AOL PERFORMANCE REQUIREMENTS  
BATHYMETRY

Excitation Wavelength	5400 Å
Excitation Bandwidth	$\leq 1 \text{ Å}$
Excitation PRF	$\geq 400 \text{ pps}$
Excitation Pulse Width	$\leq 4 \text{ nsec}$
Scanning Angle	$\pm 15 \text{ deg}$ from nadir and, fixed at nadir (non-scanning)
Scanning Rate	As required for one data point per $20 \text{ m}^2$ (constant grid desirable)
Transmitter Beam Divergence	$\leq 2 \text{ mr}$ with variable beam expander
Receiver Spectral Resolution	$5400 \text{ Å} \pm 2 \text{ Å}$ ( $< \pm 2 \text{ Å}$ desirable)
Receiver FOV	5 mr to 20 mr, variable
Receiver Temporal Resolution	2.5 nsec
Receiver Dynamic Range	$\sim 10^7$
Polarization	Required for transmitter and receiver

TABLE IV  
AOL PERFORMANCE REQUIREMENTS  
FLUOROSENSING

Excitation Wavelength	3371 Å to 6600 Å, variable with dye
Excitation Wavelength Bandwidth	1 Å at 3371 Å; 7 Å to 10 Å with dye
Excitation PRF	$\leq 100$ pps
Excitation Pulse Width	$\leq 8$ nsec
Scanning Angle and Rate	Same as for bathymetry
Transmitter Beam Divergence	$\leq 2$ mr with variable beam expander
Receiver Spectral Range	3500 Å to 8000 Å
Receiver Spectral Resolution	100 Å channels over spectral range
Receiver FOV	2 mr to 5 mr, variable
Receiver Temporal Resolution	8 nsec to 50 nsec, variable, each channel
Receiver Dynamic Range	$\sim 10^5$
Measurement Accuracy	Standard digital accuracy



TABLE V  
AOL PERFORMANCE REQUIREMENTS  
GENERAL

Operating Requirements

Mission time-line	One hour, typical
Operation with other installed systems	Required
Interface with other installed systems	Interface with LTN-51 INS and NASA 36 bit TCG required
System ground preparation time	One hour, maximum
Operator requirements	One man operation
System performance monitoring	Real time performance monitoring via scope(s), display(s), etc. required
In-flight bathymetry to fluoro-sensing interchangeability	Not required
Background monitor	Required for automatic go, no-go control
System operational altitude (unpressurized)	1,524 m (provide baro-switch to prevent operation above 1,524 m)
System non-operational altitude (unpressurized)	3,658 m
Operational relative humidity range-cabin	0 to 95%
Operational temperature range-cabin	32° to 100°F
Operational vibration profile	To be provided by NASA

TABLE V (Cont.)

Alignment and Calibration

In-flight alignment/calibration

Minimize requirements for, however, provide for transmitter/receiver alignment in-flight

Short term calibration/alignment (± one week)

Provide built-in feature with system

Transmitter output beam expander and light monitor

Required

Design and Construction

Ultimate design loading factors

Cabin area

Forward:	9 g's	Sideways:	2 g's
Down:	6 g's	Up:	3 g's

Instrument bays  
(beneath floor)

Forward:	2.5 g's	Sideways:	2 g's
Down:	6 g's	Up:	3 g's

Floor load

975 kg/m<sup>2</sup> (200 psf) maximum

In this regard, modular construction was also emphasized as highly desirable, where practicable. With regard to constraints on system weight, volume or power, no specific limitations were identified in the aforementioned areas other than that a lightweight, compact system design approach be utilized. In addition, an electronics rack space utilization of three racks maximum (two racks desired) was discussed as a design space constraint in that area. Also, discussions with D. Young of the NASA Wallops Aeronautical Program Branch<sup>3</sup> have indicated that the remaining power available, per aircraft, is 7 kW, 60 Hz, 1  $\phi$ , but that additional power could be provided, if necessary.

## SECTION III

### SYSTEM CONCEPT

#### 1.0 OPTICAL (SENSING) SYSTEM CONCEPT

##### 1.1 Concept Development

In developing the optical system concept, various alternatives were explored regarding the arrangement of the principal components, type of supporting structure, method of scanning, type of receiving optics, provision for detecting the surface return and types of spectrometers. These alternatives will be briefly discussed here in order to provide additional background and appreciation for the chosen concept.

##### A. Scanner Concept Development

Three types of scanners were considered: 1) an oscillating mirror which produces a linear scanning pattern; 2) a rotating optical wedge which produces a circular scanning pattern; and 3) a nutating mirror which produces an oval shaped scanning pattern. The nutating mirror approach was selected because it provides the most efficient distribution of data points on the water and subsurface terrain; the drive mechanism has comparatively low weight, inertia and vibration, and the extent of the scanning pattern can be adjusted by simply changing the angle of the scanning mirror.

##### B. Spectrometer Concept Development

The choice of a transmission type grating as a dispersing element was made after considering a prism and a reflectance grating. The transmission grating was found to have greater dispersive power than the prism and allowed a more compact optical system configuration than the reflectance grating.

The use of light guides and a multi-channel photomultiplier (PM) detector array was also the result of a preliminary investigation of image dissectors, vidicons, OMA detectors, etc. The light guide and multi-channel array was selected because of its high temporal and spectral information gathering ability. The capability for simultaneous recording of all

spectral channels is provided with adequate spectral resolution and very high temporal resolution.

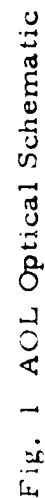
### C. Development of the Optical Configuration

Prior to the adoption of the final configuration, layouts were developed for three other candidate configurations. The first was based on a single-level platform which supported all optical components arranged generally in a straight line along the center line of the aircraft. The second configuration placed the equipment on three levels with the laser and transmitting optics on the first level, the receiver telescope at the second level and the spectrometer and bathymetry detection assemblies on the third. The third configuration was L-shaped with the transmitter components mounted to a platform on the floor of the aircraft, and the receiver components arranged vertically at the end of the platform. After careful evaluation and rejection of these approaches, the present concept was developed which rectified the shortcomings of the other approaches. In essence, the adopted configuration has the following advantages:

- a) The components are grouped in a more compact arrangement which makes better utilization of aircraft space. Adequate aisle space is provided, and restriction of access to the adjacent electronics rack area is minimized. Also, the compact package can be reasonably handled by existing support equipment during installation and removal.
- b) The laser transmitter is located in an open area on the top of the configuration in order to provide maximum accessibility and flexibility for interfacing new lasers with the system at a future date.
- c) Optimum weight and stiffness are better achieved because of the reduced length of support members.

### 1.2 Description of the Optical System Concept

The AOL optical system concept is depicted schematically in Fig. 1 (dwg 407-220). A brief description of the function of each of the major elements in the optical system is presented below.



#### A. Laser Transmitter

The choice of laser depends on the application. For bathymetry, three options presently exist:

- 1) A frequency doubled Q-switched neodymium YAG laser at 5320 Å.
- 2) A pulsed neon laser at 5401 Å.
- 3) A nitrogen pumped flowing dye laser at 5400 Å.

For fluorosensing, the only suitable candidate is a nitrogen laser at 3371 Å, used either independently or in conjunction with dye modules for transmitter wavelength variability.

Thus, this system will be designed to allow laser interchangeability in the position shown.

#### B. Laser Power and Synch Pulse Monitor

A small, fast (one nanosecond rise time) silicon diode detector will be required to monitor laser intensity and also to provide the transmit signal as a trigger signal for other components. It will require a fixed filter to ensure that the signal level is within the linear range of the detector. While it is shown at the rear of the laser, which is a useful location for those lasers having multiple outputs, with some transmitters, it may have to be mounted opposite a beam splitter which taps off a portion of the laser output if no other suitable location is available.

#### C. Filter 1

The purpose of this filter is to prevent any fluorescence generated inside the laser (dye module) discharge from reaching the receiver. It therefore will be a narrow pass filter which passes only the laser wavelength.

#### D. Polarizer (a)

In the event that the laser is not sufficiently polarized and polarization is a requirement of the experiment, a polarizer will be required in this location to provide the correct polarization.

#### E. Adjustable Beam Expander/Diverger

The purpose of the adjustable beam expander is to convert the laser beam into a beam with the correct divergence and, also, to focus the laser on the water in order to correct for altitude. It will therefore have a provision for manual operation since the aircraft altitude can vary during a mission.

#### F. Transmitter Folding Flat

This diagonal mirror directs the laser beam vertically through a hole in the receiver folding flat down to the scanning optics. Adjustments will be provided on the mirror mount so that the laser beam can be aligned with the receiver.

#### G. Receiver Folding Flat

This diagonal mirror deflects the return beam from the scanning optics into the receiver. The center hole in the mirror allows the outgoing laser beam to travel outward along the axis of the receiver and at the same time, forms a center obscuration in the receiving aperture that coincides with the obscuration produced by the telescope secondary mirror. The mirror will be aluminized and overcoated for broad-band coverage. Adjustments will be provided so that the receiver axis can be aligned to a vertical reference.

#### H. Scanner Folding Flat

This is a fixed diagonal mirror which performs the dual function of directing the outgoing laser beam to the scanning mirror and directing the return beam from the scanning mirror to the receiver.

#### I. Scanning Mirror

This is a lightweight circular mirror which will rotate about an axis which is approximately  $45^{\circ}$  from the vertical. When the mirror is adjusted so that its instantaneous FOV is at a small angle from the rotation axis, the incident beam is caused to scan in a pattern about the vertical axis. Both the outgoing laser beam and the return beams are simultaneously caused to scan while their alignment is maintained.

#### J. Receiver Telescope

For maximum sensitivity, the collecting aperture of the telescope will be slightly larger than the largest aperture available in the aircraft floor. The primary and secondary mirrors will be aluminized and overcoated for broad-band coverage. Baffles tubes are to be provided on the secondary mirror O. D. and at the hole in the primary mirror to minimize scattered light in the receiver.



K. Field Stop

The telescope will be provided with a remotely-operated field stop whose size can be varied depending on operating configuration and aircraft altitude. The field stop simultaneously acts as the entrance slit for the spectrometer.

L. Folding Flat

A  $45^{\circ}$  mirror will be located directly after the field stop to deflect the light  $90^{\circ}$  toward the collimating optics.

M. Polarizer (b)

This polarizer serves as the analyzer for the returning beam in those measurements where it is desirable to look at a particular polarization. The polarizer will have the capability to be rotated  $90^{\circ}$  by a manual control.

N. Collimating Lens

The diverging light from the field stop is collimated by this lens before entering the spectrometer and bathymetry modules.

O. Flip Mirror

The purpose of this mirror will be to direct the collimated light from the receiver to the spectrometer. When the mirror is removed, the collimated light will be transmitted directly to the bathymetry module. The mirror will have a small opening so that when it is in position for use with the spectrometer, a small portion of the return signal will also pass through the hole to the bathymetry detector which will serve as a surface return detector during both bathymetry and fluorosensing.

P. Filter 2

This filter will be a narrow band interference filter which passes only those wavelengths to be detected by the bathymetry photomultiplier. For both bathymetry and fluorosensing, these would correspond to the laser wavelength.

Q. Bathymetry Lens

This lens brings the collimated light to the proper diameter to fit the PM tube face.

#### R. Filter 4

This is a neutral density filter whose purpose is to ensure that the photomultiplier tube is always operated in its linear range, even when the signal levels are high. Accordingly, manually interchangeable filters will be required.

#### S. Photomultiplier Tube

Since the primary purpose of this PM is for bathymetry, the tube should have the highest sensitivity and speed obtainable. The output of the PM will be suitably gated, digitized and multiplexed for digital processing. It will also be available for display purposes.

#### T. Spectrometer Grating and Lens

The spectrometer optics will include a transmission grating for dispersing the light and a lens to form an image of the spectrum. The concept is to provide the required resolution and high efficiency over the broad spectral range required in the fluorosensing application.

#### U. Filter 3

A filter, placed near the focal plane of the spectrometer, will be required for the purpose of blocking the second order blue spectrum which would otherwise overlap the first order spectrum.

#### V. Multi-Channel Detector

The output of the spectrometer will be fed to forty detector channels.<sup>(1)</sup> Each channel will include a small, end-on, photomultiplier tube. The feed will be by means of light guides from the spectrometer to each photomultiplier. If possible, the PM photocathodes will be selected in such a way as to optimize the quantum efficiency for the wavelength of the channel in which that particular PM is being used. This may be done in major groups. The PM's will be mounted together in a compact volume and, if possible, operated from a common power supply with electrical isolation between the photomultipliers. The output of each PM will then be suitably gated, digitized and multiplexed for digital processing.

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<sup>(1)</sup> Forty channels were selected by the Design Team over the spectrometer spectral range (3500-8000 Å) to optimize the utilization of the data acquisition electronics between the bathymetry and fluorosensing portions of the system. Each channel would therefore encompass  $3500 \text{ Å} / 40 = 112.5 \text{ Å}$ .

#### W. Footprint Camera

A wide field-of-view, slow framing rate camera will be required, located in a separate aircraft viewing port, to provide ground truth data. Its shutter will be suitably synched to provide a timing correlation with the transmitted laser pulse(s).

#### X. Optical Platform

The optical platform will be a two-tiered structure which supports transmitter elements on the top level and receiver elements on the lower level. The stiffness of the structure will maintain the alignment of the transmitter to the receiver. The optical platform will attach to the floor of the aircraft, over an existing access hatch, so that the optical path can pass through the hatch to the scanning optics beneath the floor. The scanning assembly will be rigidly attached to the optical platform by means of stand-offs which pass through the floor so that alignment will be maintained between the scanning optics and the transmitter/receiver assembly.

### 2.0 ELECTRONIC SYSTEM CONCEPT

Once the basic AOL measurement and performance requirements were established, emphasis was placed on the development of an electronic system conceptual block diagram, which could be supported by off-the-shelf equipment to satisfy the system's data gathering and all other support requirements (timing, control, gating, housekeeping, processing status and performance verification displays, recording, etc.). The requirements for each of the aforementioned areas were investigated separately and then common items were merged to reflect a system flexible enough to satisfy the basic requirements for both bathymetry and fluorosensing.

#### 2.1 Concept Development

##### 2.1.1 Bathymetry

The AOL bathymetry application was determined to require a 400 pps laser transmitter and a receiver detection assembly and acquisition electronics which could temporally resolve surface and bottom returns to a resolution of 2.5 nsec. To meet the system measurement and performance goals, the detector for this application requires fast response, high gain and optimum quantum efficiency in the 540 nm spectral region. Once the optical signal has been transformed to its electrical analog, a method must

be provided to capture the temporal waveform and convert it into a form suitable for recording. With these basic requirements in mind, a survey was conducted to select the key system items, e. g. , a photomultiplier detector and the data acquisition electronics, having the appropriate characteristics for the application. (The results of the photomultiplier survey will be detailed in the Preliminary Design Section of this report due to the critical requirements for this item in the performance of the system.)

With regard to the data acquisition electronics, the first unit considered was the Lecroy WD2000 Waveform Digitizer which could sample and resolve phenomena of nanosecond duration and provide a computer compatible digital output. One limitation which would dictate the use of at least two of these expensive units in the system was that each is only capable of storing 20 discrete samples, and to meet the measurement depth and resolution requirements, approximately 40 discrete samples would be necessary. A Biomation 8100 unit solves the problem of insufficient samples, providing 2000 bins, but the maximum sample time resolution is 10 nsec which is far too coarse for the application. Two other possibilities using a modular CAMAC instrumentation approach were then considered. Lecroy Research Systems manufactures a Model 2249A, 12-channel A/D converter which will soon be available in a separate gate version (Model 2249SG) that can be sequenced at intervals of less than 10 nsec. No quantitative information could be obtained from the vendor as to the minimum gate which could be reliably guaranteed, but his estimate of the latter was of the order of 5 nsec. A similar unit, having less channels, is manufactured by EGG/ORTEC (the QD 410 Charge Digitizer) which provides 4 channels per module with 10-bit resolution at gate widths specified at  $< 5$  nsec. The vendor agreed to run differential linearity tests using a 2.5 nsec gate width, with channels 50 to 300 and found that the differential nonlinearity could be held to  $\pm 290$ . This item was determined to be the only unit available to date which could reasonably provide the high-speed, single-event waveform recording necessary for bathymetry data acquisition. Further characteristics of this unit will be presented in subsequent sections of this report.

### 2.1.2 Fluorosensing

The AOL fluorosensing application requires a light dispersing receiver detection assembly to accept the laser induced fluorescent returns from the water surface at up to a 100 pps repetition rate over a bandwidth from 350 nm to 800 nm. Since fluorescent lifetimes have been predicted to be in the order of from 8 to 50 nsec (see Table II), it is necessary that a variable means be provided to gate return signals to match these predicted lifetimes for best signal-to-noise performance. The most critical parameters for any potential detector assembly are:

- a) Fast response time (within several nanoseconds).
- b) Simultaneous, multi-channel data recording capability.
- c) Fast data readout (within several hundred microseconds).
- d) Tolerance to relatively high average input photon flux rates (ambient daylight).
- e) Photon-noise-limited performance (since only a very small number of signal photons may be received in some channels during a measurement period).
- f) Wide dynamic range (because the total number of signal photons received during a measurement period may vary by  $10^3$  from channel to channel).

A number of electro-optical sensors have been evaluated against these criteria. One, designed about an image dissector, or a commercially available "Optical Multi-Channel Analyzer", might seem to be a logical choice for this application. Basically, however, conventional image tubes would only marginally suffice because of their slow (in this context, at least) response time and data rate handling capability. No doubt a custom-made unit could be designed and fabricated (i.e., such as the devices described in Refs. 4 and 5), but the time and cost involved would be prohibitive. In any case, it would be a poor match of sensor to mission, since for this application only forty resolution cells are required, and image tubes usually possess  $10^5$  or more pixels.

Photodiodes are small, inexpensive, have high quantum efficiency and possess very fast response times. However, at the lowest photon levels under consideration in this case, even the "avalanche" types of

photodiodes fail to have enough internal gain to produce a charge pulse ( $10^{-15}$  coulombs or greater) detectable with present state-of-the-art charge-sensing preamplifiers. Digicons and image intensifier combinations were also investigated but were found to have relatively slow response and gate lag problems not easily overcome and would require considerable development effort. After surveying all of the most recently developed sensors that could conceivably satisfy this application, a more conventional approach seemed to be the most feasible. This consists of a matrix of individual photomultiplier tubes, fiber-optically coupled to a common spectrometer focal plane. Such an approach has a number of apparent advantages: it employs the well-established technology of PMs; each PM photocathode can be chosen for maximum quantum efficiency in the particular portion of the spectrum it must cover; individual PMs can be easily replaced; they can be gated in a variety of ways; have nanosecond response time, high gain, large dynamic range and easily processed output signal levels. <sup>(6)</sup>

## 2.2 Description of the Electronic System Concept

The final system concept arrived at as a result of the preceding investigations and tradeoffs related to each application will now be described along with the data and system support requirements and interfaces. The AOL electronics system will be comprised of two main sections, the control and data acquisition subsystem and the signal processing subsystem. The block diagram shown in Fig. 2 (dwg 407214) depicts the interrelationship between units and the general signal flow. Each section is described below including the major functions associated with each module or unit within a subsystem.

### 2.2.1 Control and Data Acquisition Subsystem

The primary purpose of the control and data acquisition subsystem is: (1) to generate and distribute all necessary signals and synchronize the transmission and reception of system data; and (2) to properly receive and acquire both bathymetry and fluorosensing signals. In order to satisfy these requirements, a combination of Nuclear, CAMAC and MECL logic units have been chosen and configured as shown in Fig. 2. The major functions performed by the control and data acquisition subsystem are: (1) to determine the aircraft altitude accurately and in a time frame consistent

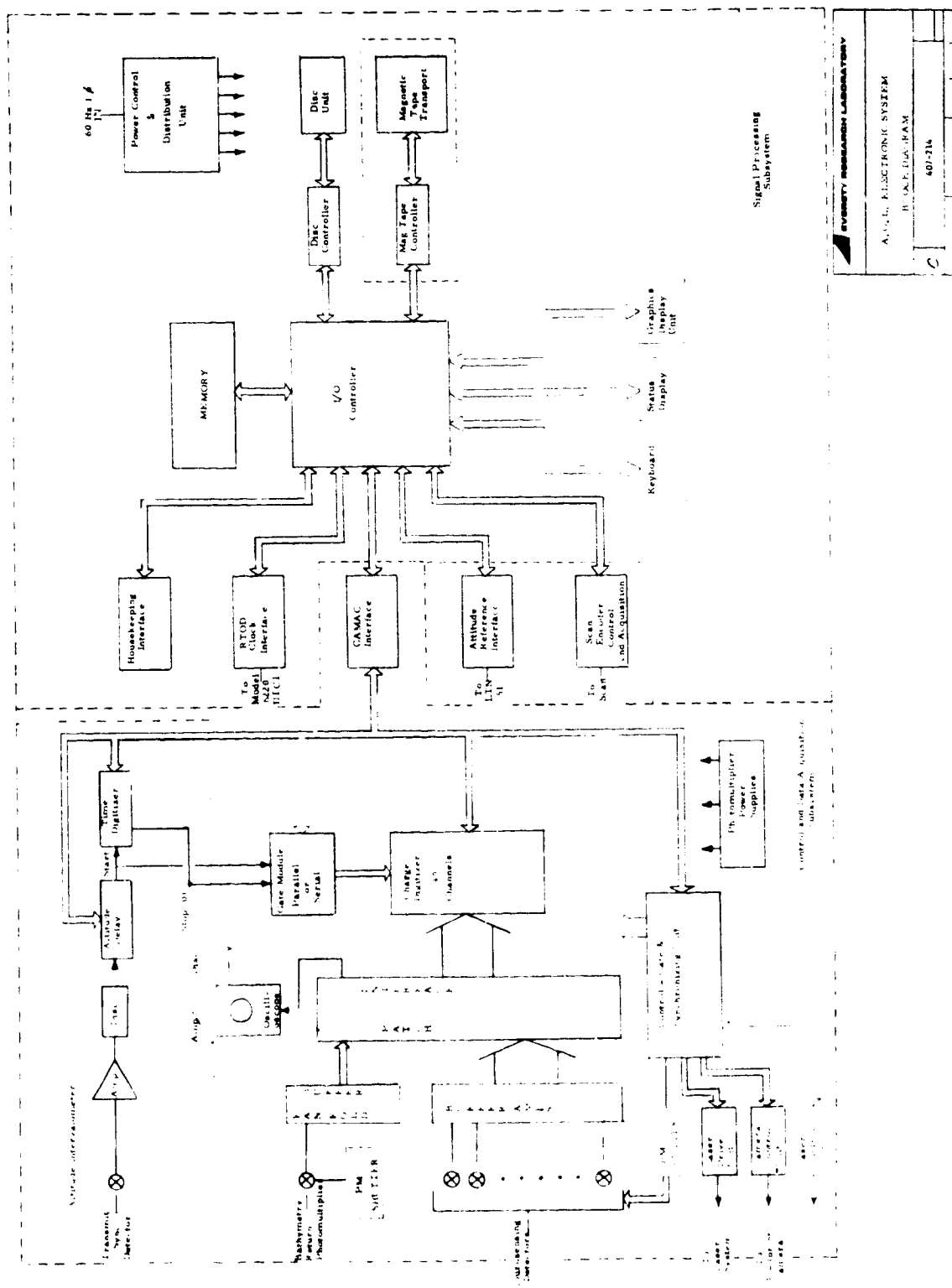


Fig. 2 AOL Electronic System Block Diagram

with experiment requirements; (2) to acquire and digitize both bathymetry and fluorosensing return signals; and (3) to control, gate and synchronize the control and data acquisition subsystems properly in the various modes.

#### A. Altitude Intervalometer

The combination of blocks shown in Fig. 2 will provide the means necessary to actually determine aircraft altitude on per-pulse basis. The altitude delay generator will provide the mechanism for delaying the start of the time digitizer, consistent with aircraft altitude. In other words, the nominal laser transmit and return time will be programmed by the delay generator such that its output will occur two to three meters prior to the actual surface return. This output will then start the time digitizer to accurately determine the number of nanoseconds which have elapsed before reception of the surface return signal. By knowing the program delay set into the altitude delay generator and adding the time digitizer output, the total round-trip time of the laser and therefore aircraft altitude can be determined. An iterative sample averaging and updating technique within the computer will be used to continuously program the delay generator to compensate for aircraft altitude and sea state variations. The altitude intervalometer will be implemented using a transmit synch detector, a buffer amplifier, threshold discriminator, a detector delay generator, a time digitizer, a surface return detector and a set of buffer amplifiers and threshold discriminators, as shown in Fig. 2.

#### B. Data Acquisition

For bathymetry, the output of the bathymetry photomultiplier will be distributed into a 40-channel fan fold buffer and, through an appropriate patching interface, will be presented to the input of the charge digitizers. The fluorosensing path interfaces the 40 individual detectors to the charge digitizer through the buffer amplifiers. This will allow the outputs of each detector to be processed simultaneously.

The gate module shown in the figure provides the logic to sequentially gate (bathymetry) each of the charge digitizers or parallel gate (fluorosensing) all of the charge digitizers simultaneously. This unit will be implemented using a combination of MECL III and MECL 10,000 logic devices. For bathymetry, sequential gating separated by  $\sim 2.5$  nsec can be achieved



and for fluorosensing, a 10 to 50 nsec variable width gate will be generated consistent with experiment aperture requirements.

### C. Control/Gating and Synchronizing Unit

The control/gating and synchronizing unit will be implemented using MECL logic to properly interface with the items shown, for the purpose of "fast" (nanosecond) unit synchronization.

#### 2.2.2 Signal Processing Subsystem

The signal processing subsystem portion of Fig. 2 indicates the various units that are necessary to implement and support an application of this type. The CPU will include all of the interfaces to accept signal data, housekeeping, mode control, aircraft attitude, real-time-of-day and encoded scan signals for real-time processing, and provide format control to subsequently record all pertinent information.

The keyboard will furnish the means to make mode control changes. A status display will be provided to indicate the current status and settings of critical system functions. The graphics display unit, via appropriate programming, will display data graphically for performance verification purposes. It will also be used as a real-time means of plotting spectral or time history information. A magnetic tape transport is included to record all required experiment and housekeeping data for subsequent processing and data reduction. The disc unit will store application and diagnostic programs as well as raw data during real-time data acquisition. Data editing of extraneous (noise) information will be accomplished between data gathering intervals as the data is transferred from the disc to magnetic tape.

The power control and distribution unit will provide the power interface to the aircraft. This unit will include appropriate filtering, power protection and power status indicators.

#### 2.2.3 System Timing Diagram

A system timing diagram is shown in Fig. 3. Once the system start command has been issued, synchronization of all subsystems, CAMAC or CAMAC-related items will be controlled within the control gate and synchronizing unit. A stable oscillator with an incremental countdown clock will be used to set the pulse repetition rate of the laser (400 pps for bathymetry, 100 pps for fluorosensing, and possibly a few binary related rates)

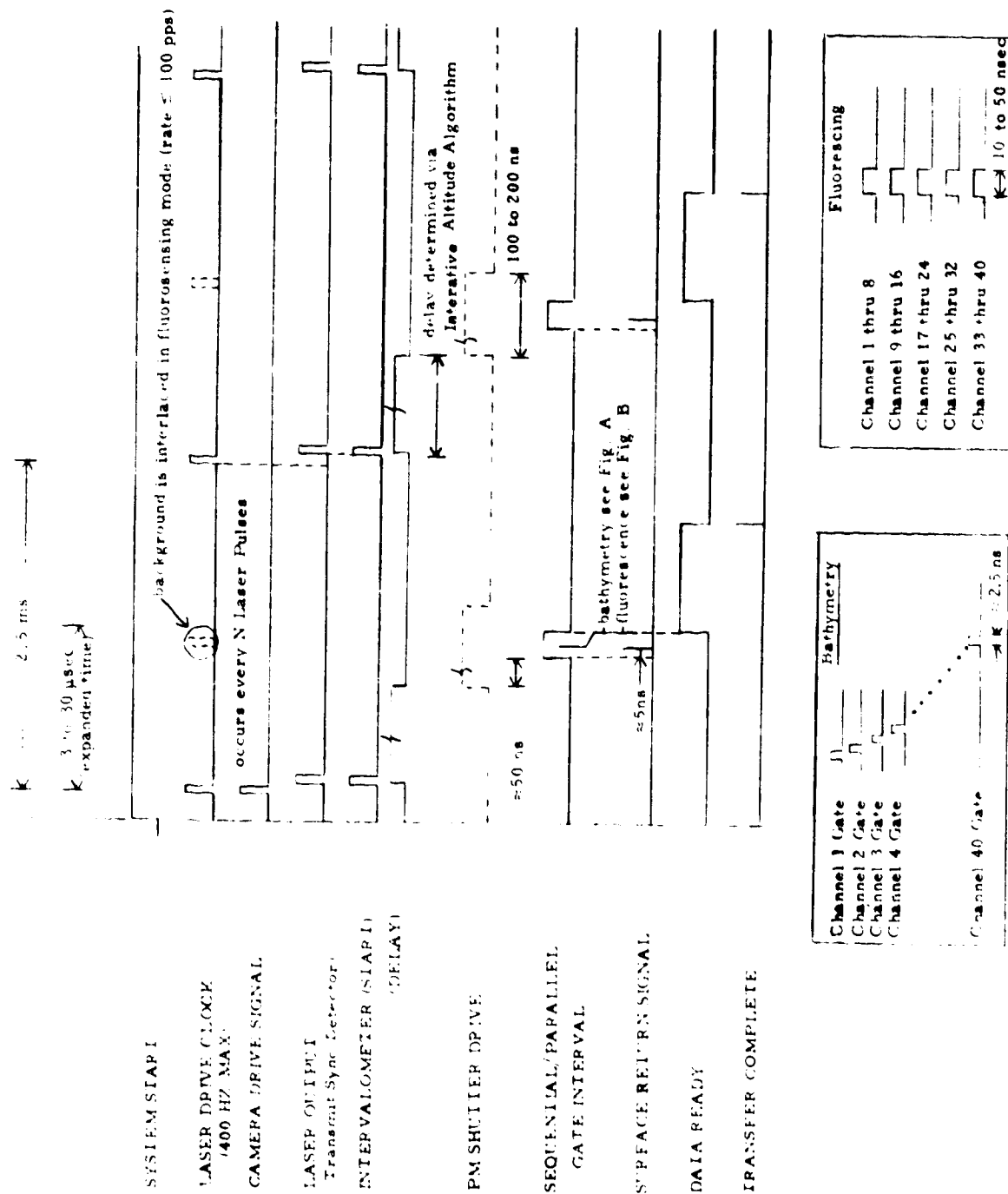


Fig. 3 System Timing Diagram

The main synchronization of all high-time resolution elements will commence at the instant laser light exits from the transmitter, as detected by the transmit sync detector. This signal will start the altitude intervalometer delay generator which will be programmed on a per-pulse basis to time out approximately 50 nsec prior to receiving a surface return. Appropriate fixed delays will be incorporated to initialize the gate module triggering in either mode approximately 5 nsec before detection of the surface return. The gate will then produce the pulse sequences shown on the inserts in Fig. 3. The surface return signal will stop the time digitizer to complete the altitude intervalometer cycle. After the time digitizer and charge digitizers have completed their A/D conversions, a data-ready signal will interrupt the computer to transfer this information. A transfer-complete signal will then be issued from the I/O controller to reset all data registers and then wait for the next cycle.

## SECTION IV

### PERFORMANCE CALCULATIONS

#### 1.0 INTRODUCTION

This section contains calculations related to bathymetry and fluorosensing radiometric system performance, eye safety, horizontal measurement accuracy in the bathymetric mode and scan pattern characteristics for the chosen scanning approach.

#### 2.0 RADIOMETRIC SYSTEM PERFORMANCE

##### 2.1 Optical Efficiency

An essential element in the calculation of the various system performance parameters is the optical efficiency of the various system components. Table VI presents a summary of the estimated component efficiencies, using the optical system concept discussed in Section III and considering the specifications defined in Section V of this report. These efficiencies will be used in all subsequent calculations.

##### 2.2 Signal-To-Noise, Bathymetric Mode

The calculation of radiometric signal return from the ocean floor in the bathymetric mode is determined from Eq. (1).

$$P_{rB} = \frac{P_t R (1 - \rho) e^{-2a_1 h} e^{-2\gamma d} A_c \tau_{SB}}{\pi (h + \frac{d}{n})^2} \quad (1)$$

where

- $P_{rB}$  = Received power at photomultiplier, bathymetric mode
- $P_t$  = transmitter power (30 kW)
- $R$  = bottom reflectivity (15%)
- $\rho$  = surface reflectivity (2%)

TABLE VI  
AOL OPTICAL EFFICIENCIES

	No. of Surfaces	Efficiency	Subtotal	Total
1. Bathymetric Mode				
A. Transmitter				
1. Dielectric coated mirrors	2	.98	.96	
2. Aluminum coated mirrors	3	.88	.68	
3. Polarizer	1	.35	.35	
4. Beam expander, coated optics	4	.98	.92	
Transmitter efficiency $\tau_{TB}$				.211
B. Receiver				
1. Aluminum coated mirrors	6	.88	.46	
2. Lens surfaces	4	.98	.92	
3. Interference filter	1	.40	.40	
4. Polarizer	1	.35	.35	
Receiver efficiency $\tau_{RB}$				.060
Total system efficiency $\tau_{SB}$				.0127

TABLE VI (continued)

	No. of Surfaces	Efficiency	Subtotal	Total
II. Fluorosensing Mode				
A. Transmitter				
1. Dielectric coated mirrors	2	.98	.96	
2. Aluminum coated mirrors	3	.88	.68	
Transmitter efficiency $\tau_{TF}$				.65
B. Receiver				
1. Aluminum coated mirrors	7	.88	.41	
2. Lens surfaces	4	.98	.92	
3. Lightpipe efficiency	1	.80	.80	
4. Grating efficiency (typical)	1	.60	.60	
Receiver efficiency $\tau_{RF}$				.18
Total system efficiency $\tau_{SF}$				.118

- $a_1$  = atmospheric transmission at 5400 Å (0.12/km)
- $\gamma$  = effective attenuation coefficient of seawater - (0.2/m)
- $A_c$  = area of collector (0.073 m<sup>2</sup>)
- $\tau_{SB}$  = system efficiency, bathymetric mode (1.27%)
- $h$  = A/C altitude (609 m)
- $d$  = water depth (10 m)
- $n$  = index of refraction of seawater (1.33)

Introducing the above values, we obtain a receiver power,  $P_{rB}$ , of  $3.06 \times 10^{-8}$  W. Some of the assumptions which go into Eq. (1) are as follows: the appearance of the index of refraction in the denominator accounts for the bending of the up-welling radiation as it passes through the water-air interface. A 30 kW transmitter power was selected<sup>(1)</sup> in order to arrive at a conservative estimate of the signal return. The atmospheric transmission was obtained from Reference 7 and the seawater attenuation coefficient  $\gamma$  was obtained from Reference 8 as being comparable to an  $a = 1.0$  per meter. The bottom reflectivity of 15% was chosen as a typical value.

Equation (2) provides an estimate of the background noise power,  $P_{NB}$ , which arrives at the receiver due to the up-welling radiation from the ocean during full sunlit illumination.

$$P_{NB} = I_s A_s \Delta\lambda_B \frac{A_c}{h^2} \tau_{RB} e^{-a_1 h} \quad (2)$$

where

- $I_s$  = background spectral radiance (10 W/m<sup>2</sup> -  $\mu$ -ster)
- $A_s$  = surface area of seawater which falls within the field-of-view of the receiver (48 m<sup>2</sup> for a 13 milliradian receiver field-of-view at 609 meters altitude)
- $\Delta\lambda_B$  = receiver bandwidth ( $4 \times 10^{-4}$   $\mu$ )

<sup>1</sup>The Avco C950 N<sub>2</sub> pumped dye laser, operating at 5400 Å, was assumed in arriving at the transmitter power.

$\tau_{RB}$  = receiver optical efficiency (6.0%)

For the purpose of this calculation, we have assumed the receiver spectral bandwidth of 4 Å will be provided by the bathymetry interference filter and we have selected a receiver field-of-view of 13 mr. This value is arrived at by extrapolating the results of Kim<sup>8</sup> to obtain an estimate of the value which will optimize the signal-to-noise with a 3 mr transmitter beam divergence. This yields a value of  $P_{NB}$  of  $2.2 \times 10^{-9}$  W. When this received power is converted to photons, it yields 15 photons in a 2.5 nsec gate. The signal power  $P_{rB}$  corresponds to 209 photons in the same gate interval. If we assume a photomultiplier quantum efficiency of 10%, then the number of signal photoelectrons,  $\phi_S = 21$  and the number of background photoelectrons,  $\phi_B = 1.5$ . For  $m$  pulses, the signal-to-noise ratio is given by

$$\frac{S}{N} = \frac{\sqrt{m \phi_S}}{\sqrt{\phi_S + 2\phi_B}} \quad (3)$$

Thus, for a single pulse, the S/N in the bathymetry mode is 4.3 for conditions chosen.

### 2.3 Signal-To-Noise, Fluorosensing Mode

Equation (4) is a calculation of the power returned to each channel of the spectrometer when the system is operated in the fluorosensing mode.

$$P_{rF} = \frac{P_t \eta_f \Delta\lambda e^{-(a_1 + a_2) h'} A_c \tau_{SF}}{(h')^2} \quad (4)$$

where

$\eta_f$  = fluorescence conversion efficiency ( $10^{-4} \mu^{-1} \text{-ster}^{-1}$ )

$\Delta\lambda$  = spectrometer channel bandwidth ( $1.4 \times 10^{-2} \mu$ )

$a_2$  = atmospheric transmission at 3371 Å (0.32/km)

$\tau_{SF}$  = system efficiency, fluorosensing mode (11.8%)

$h'$  = aircraft altitude, fluorosensing mode (152 m)

In the fluorosensing mode, the operating altitude is assumed to be 152 meters, the downward transmission occurs in the UV and the upward transmission



at a typical wavelength in the visible. This yields a value of  $P_{RF}$  of  $1.5 \times 10^{-8}$  W for a transmitter power/pulse of 30 kW. If we assume a laser pulse width of 5 nsec and convert to photons, then this corresponds to 202 photons/pulse.

An estimate of the background noise energy in each channel of the receiver in the fluorosensing mode,  $E_{NF}$ , is given by Eq. (5).

$$E_{NF} = \frac{I_s A'_s t_g \Delta\lambda e^{-a_1 h'} A_c \tau_{RF}}{h'^2} \quad (5)$$

where

- $A'_s$  = surface area of seawater which falls within receiver field-of-view ( $0.16 \text{ m}^2$  for a 3 milliradian receiver field-of-view at 152 m altitude)
- $t_g$  = receiver gate (15 nsec)
- $\tau_{RF}$  = receiver efficiency, fluorosensing mode (18%)

where we have assumed a receiver gate of 15 nsec as a typical fluorescent decay lifetime for materials which may be of interest for remote sensing. Also we have assumed an  $A_s$  corresponding to a 3 mr field-of-view. This yields a value of  $1.9 \times 10^{-16}$  joules/channel, which when converted to photons is 524 photons/channel.

We can now ask the question as to how many pulses must we integrate to obtain a signal to noise of 10. Again, using a photomultiplier quantum efficiency of 10% and Eq. (3), we obtain a value for the number of pulses,  $m$ , of 31. At a repetition rate of 100 pulses per second, this is less than 1/3 second and corresponds to a distance covered over the ground of 25 meters for an aircraft velocity of 80 meters per second (150 kts).

## 2.4 Altitude Intervalometer Performance

### 2.4.1 Fluorosensing Mode

Equation (6) is a calculation of the power returned to the receiver when the bathymetric photomultiplier is being used as an altitude intervalometer in the fluorosensing mode.

$$P_s = \frac{P_t \rho_s e^{-2\alpha_2 h'} A_c \tau_{TF} \tau'_{RB} a_m}{2\pi h'^2} \quad (6)$$

where

- $P_s$  = received power at photomultiplier from water surface
- $\rho_s$  = diffuse scattering coefficient of the sea surface (0.25%)
- $\tau'_{RB}$  =  $\tau_{RB}$ , without polarizer (17%)
- $a_m$  = % of return beam thru aperture in the two position flip mirror (1%)

This yields a value of  $4.1 \times 10^{-8}$  W for the signal returned.  $\rho_s$  is an estimate of the scattering coefficients of the surface of seawater for incident radiation into  $2\pi$  steradians and  $a_m$  is the fraction of the beam passed through a small aperture in the flip mirror which permits some of the energy of the main beam to arrive at the bathymetric photomultiplier when the system is in the fluorosensing mode.

Equation (7) is a calculation of the background noise power returned to the receiver under the same conditions as above.

$$P_b = \frac{I_s A'_s e^{-\alpha_s h'} A_c \Delta\lambda_f a_m \tau'_{RB}}{h'^2} \quad (7)$$

where

- $P_b$  = received daylight background power, bathymetry
- $\Delta\lambda_f$  = fluorosensing mode, bathymetric photomultiplier interference filter passband ( $.02\mu$ )

We have assumed a surface area corresponding to a 3 milliradian field-of-view and a spectral filter with  $200 \text{ \AA}$  bandwidth. This yields a value of background of  $1.6 \times 10^{-10}$  W which is clearly negligible compared to the signal power.

#### 2.4.2 Bathymetric Mode

In the bathymetry mode, the first surface return is used as a signal both for the altitude intervalometer, and the actual bathymetric measurement.

To estimate the strength of the first surface return, we use Eq. (8).

$$P_s = \frac{P_t \rho_s e^{-2a_1 h} A_c \tau_{SB}}{2\pi h^2} \quad (8)$$

This yields a signal power of  $2.9 \times 10^{-8}$  W. This is a conservative lower limit since we assumed a very low value of  $\rho_s$ .

The background calculation in this case comes from Eq. (9).

$$P_b = \frac{I_s A_s e^{-a_1 h} A_c \Delta\lambda_B \tau_{RB}}{h^2} \quad (9)$$

In this case, this yields a background power of  $2 \times 10^{-9}$  W. Again the signal power is substantially above the background power.

## 2.5 Eye-Safety Considerations

An eye safety calculation was performed for AOL operation in the flurosensing mode from an altitude of 152 meters with a beam spread of 3 milliradians assuming a 150 microjoule transmitter with a wavelength between 4000 Å and 7000 Å. This yields an energy on the surface of  $5 \times 10^{-8}$  joules/cm<sup>2</sup>. The ANSI eye-safe limit for a system with these parameters and operating at 100 pps permits  $5 \times 10^{-8}$  joules/cm<sup>2</sup> energy to fall on the cornea of an eye with a pupil diameter of 7 mm. Therefore, this operating condition meets the unaided eye requirements for eye-safety. When a transmitter having power in excess of the latter is used with the system, beam expansion will be a requirement.

## 2.6 Horizontal Absolute Position Measurement Error - Bathymetry Mode

An estimate was made of the absolute horizontal measurement accuracy in the bathymetric mode. When flying at an altitude of 609 meters, the absolute position error  $E_R$  is given by Eq. (10).

$$E_R = \left[ A_p^2 + \gamma_a^2 + A_a^2 + E_s^2 + E_d^2 + O_p^2 + A_f^2 \right]^{1/2} \quad (10)$$

where

- $A_p$  = A/C absolute position uncertainty = 3.3 m (using Cubic autotape system)
- $\gamma_a$  = A/C attitude uncertainty using the LTN-51 ( $\epsilon_{roll} = \epsilon_{pitch} = \epsilon_{yaw} = 0.20^\circ$ ) = 2.12 m for each axis
- $A_a$  = A/C altitude uncertainty  $\approx 0$
- $E_s$  = scan encoder readout uncertainty =  $5.6' = 1$  m at 609 m
- $E_d$  = scan encoder digitization error =  $0.02^\circ = 0.2$  m at 609 m
- $O_p$  = optical platform component alignment error and platform misalignment with datum (0.18 m in each of two elements, and 0.212 m in a third)
- $A_f$  = optical axis misalignment from datum due to A/C flexure

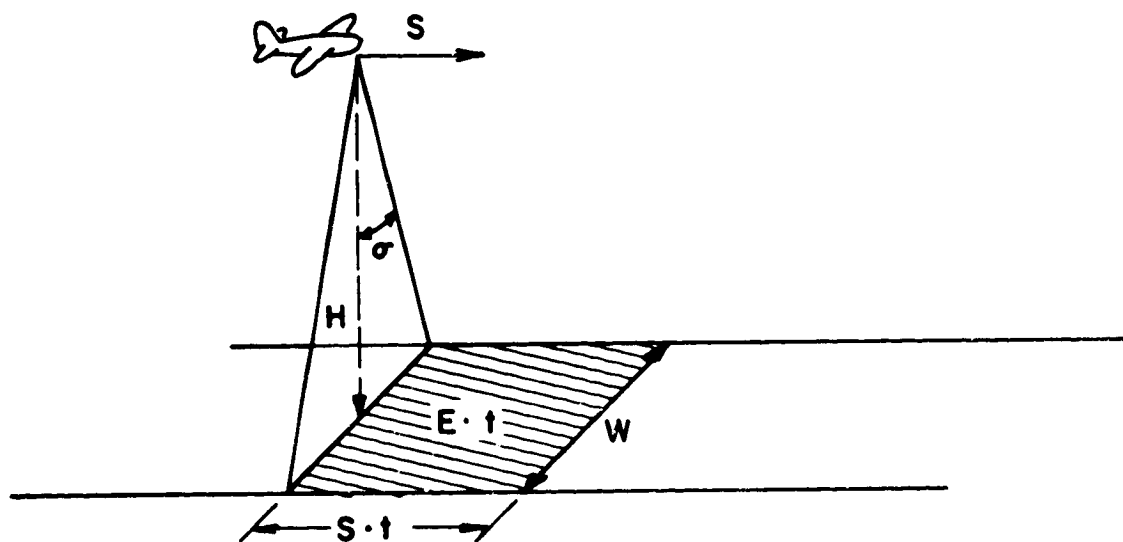
This yields a value of  $E_R = \left[ 25.5 + A_f^2 \right]^{1/2}$ . Therefore, in the absence of A/C flexure between the LTN-51 INS platform and the AOL optical platform, the estimated absolute horizontal measurement accuracy in the bathymetry mode of operation is about 5 meters.

## 2.7 Scanning Considerations

### 2.7.1 Laser Pulse Repetition Rate

The operational parameters of an aircraft speed and altitude, permit it to address a certain area of the earth's surface per unit time. If we divide that area into resolution elements, we obtain the conditions on scan angle and laser pulse repetition frequency (PRF) for symmetrical ground coverage. Referring to Fig. 4, let

- $W$  = width on the earth's surface of the area addressed during scanning
- $h$  = aircraft altitude
- $\sigma$  = scanning half angle



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Fig. 4 Basic Scanning Geometry

S = speed of aircraft  
 t = time interval considered

Then  $W = 2A \tan \sigma$ .

If E is the total area addressed by the aircraft per unit time, then

$E = 2HS \tan \sigma$ .

If we divide E by the laser pulse repetition frequency, R, we obtain the mean surface area addressed by each laser pulse, D, where

$$D = \frac{2HS \tan \sigma}{R}$$

(Note that  $1/D$  is the density of pulses per unit area.) If we require D to be no larger than a certain value, this establishes a minimum value for R which will cover the addressed area. If we select

$$D = 20 \text{ m}^2 (215 \text{ ft}^2)$$

$$S = 76 \text{ m/sec (250 ft/sec)}$$

Then the minimum laser pulse repetition rate, R, required for one data point in  $20 \text{ m}^2$  is as shown in Table VII, from which we conclude that with an operating altitude of 609 m (2000 ft.), a 76 m/sec (150 kt) aircraft and a PRF of 400, a scan angle of  $5^\circ$  is the largest angle that can be utilized to completely cover the required resolution cell. However, since one use for the AOL is to evaluate large scan angles, provision for angles up to  $15^\circ$  will be included.

### 2.7.2 Properties of Circular Scans

If we let a scanner rotation rate = f cycles per second =  $2\pi f$  radians/sec, then the time of rotation =  $1/f$ . Therefore, in one scanner rotation, the aircraft advances  $S/f$  and the time between laser pulses =  $1/R$ . In this time, the scan moves  $\frac{W}{2} (2\pi f) \left(\frac{1}{R}\right)$ , where

$$D = \left(\frac{S}{f}\right) \left(\frac{W \pi f}{R}\right) = \frac{\pi S W}{R} = \frac{2\pi S H \tan \sigma}{R}$$

If we interlace scans, then  $D = 1/2 \left[ \frac{2\pi S H \tan \sigma}{R} \right] = \frac{\pi}{2}$  (rectangular scan).

TABLE VII  
MINIMUM PRF VS SCAN ANGLE AND AIRCRAFT ALTITUDE

$\sigma$ \ H	152 m	304 m	456 m	609 m
5°	102	204	306	408
10°	205	410	615	820
15°	312	624	936	1248
20°	423	846	1270	1693

Since the mean density of points is the same as the rectangular scan, the density is reduced in the center by  $\frac{2}{\pi}$  and increased at the edges to compensate, therefore, it is seen that area coverage is independent of the rotation rate of scanner.

$$\text{Scan Rectangularity} = \frac{\pi W f}{R} \cdot \frac{f}{S} = \frac{\pi W f^2}{R S} = \frac{2 \pi H \tan \sigma}{R S} f^2$$

With interlaced scans, rectangularity =  $\frac{\pi W f}{R} \frac{2f}{S} = 2$  (rectangularity without interlace).

In Table VIII is shown the ratio of scan pattern transverse motion to forward motion (rectangularity) vs scanner rotation rate, with and without interlacing, for an aircraft at a 609 m (2000 ft) altitude, a scan angle of  $5^\circ$ , a PRF of 400, and a velocity of 76 m/sec (150 kts).

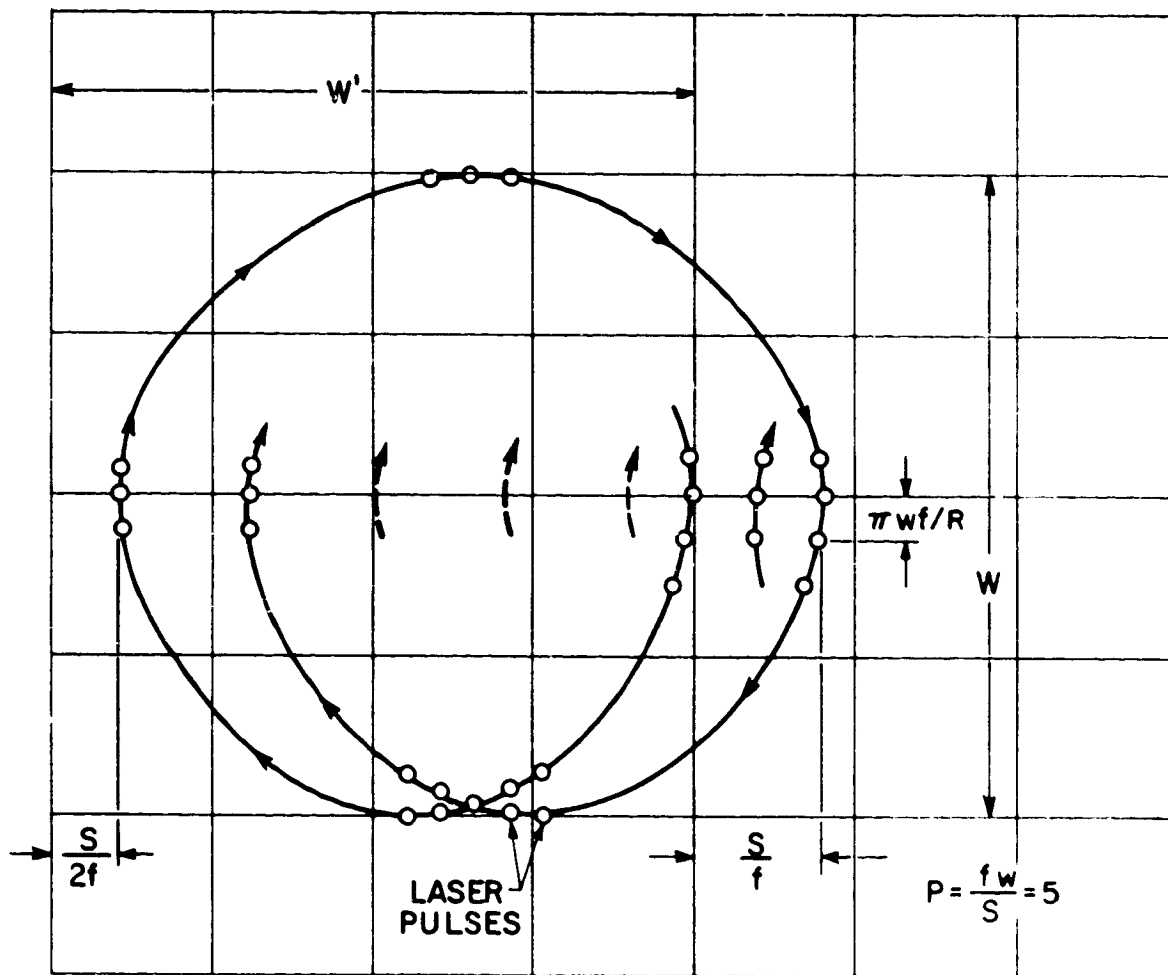
With regard to scan pattern interlace symmetry and referring to Fig. 5, if the forward motions of sequential scan passes is defined as  $X = m (S/f)$ , where  $m = \text{integer}$ , then rear scan passes are located at  $X = -W' + \frac{1}{2} \frac{S}{f} + n \frac{S}{f}$ , where  $n = \text{integer}$ . However, we want the rear pass to be located at  $X = m (S/f) + 1/2 S/f$ , which occurs if  $m \frac{S}{f} = n \frac{S}{f} - W'$  or  $(m - n) = \frac{f W'}{S} = \text{integer} = p$ , where  $f = p \frac{S}{W} = p \frac{S}{2A \tan \sigma}$  for a circular scan. Table IX shows the conditions of  $f$  and  $p$  for symmetrical forward and rearward scan pattern rectangularity for an aircraft at 609 m (2000 ft), having a velocity of 76 m/s (150 kts) with a  $5^\circ$  scan angle.

### 2.7.3 Properties of a Rotating Scan Mirror

#### A. Analysis

In order to calculate the path of a ray emerging from a rotating scan mirror, we start with a coordinate system related to the scanning mirror (see Fig. 6). The  $\hat{z}$  axis is the axis of rotation, the  $\hat{y}$  axis is in the plane defined by the axis of rotation and the entering unit ray  $\hat{S}_0$ , and the  $\hat{x}$  axis is normal to this plane.  $\beta$  is the angle between  $\hat{S}_0$  and the positive  $\hat{z}$  axis.  $\hat{N}$  is the normal to the mirror and  $\alpha$  is the angle between  $\hat{N}$  and the  $\hat{z}$  axis. As the mirror rotates about  $\hat{z}$ , it rotates through an angle  $\gamma$ . When  $\gamma = 0$ ,  $\hat{N}$  is on the first quadrant of the  $\hat{y}$ - $\hat{z}$  plane.





E949 4

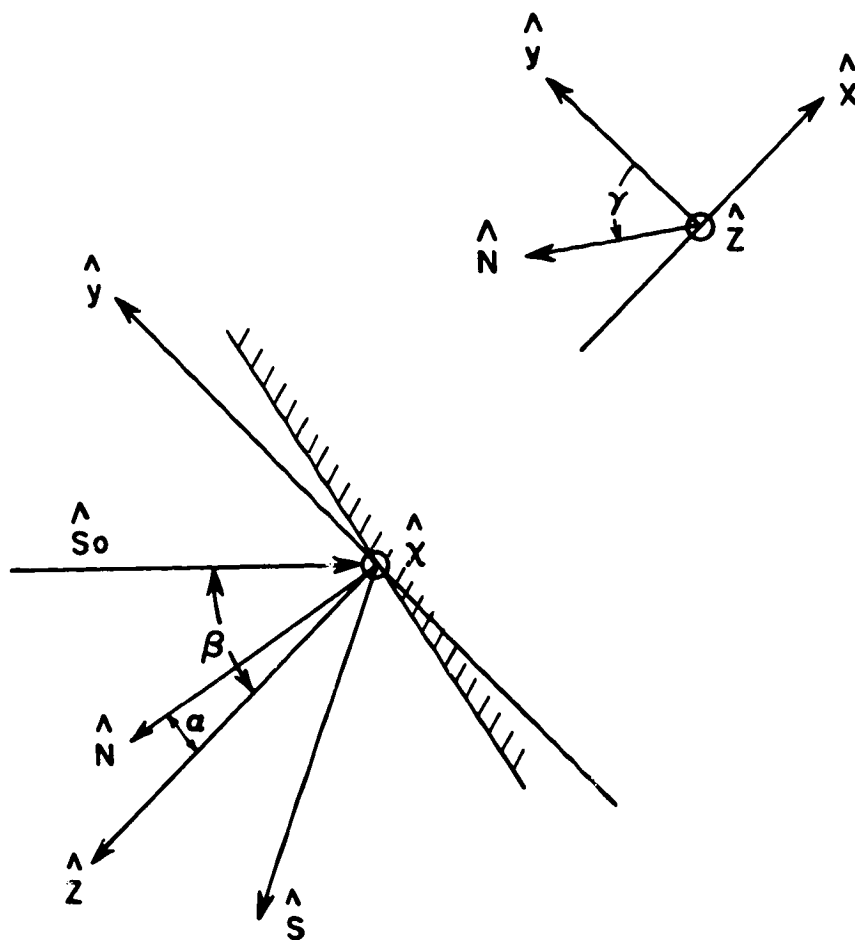
Fig. 5 Scan Pattern Interlace

TABLE VIII  
SCAN PATTERN RECTANGULARITY VS SCANNER ROTATION RATE

f cps	Scan Rectangularity (no Interlace)	Scan Rectangularity (with Interlace)
1	.01	.02
2	.04	.08
4	.16	.32
5	.25	.50
6	.36	.72
7	.49	.98
10	1.0	2.0

TABLE IX  
SYMMETRICAL SCAN PATTERN RECTANGULARITY VS  
SCANNER ROTATION RATE

f cps	p	Scan Rectangularity with Interlace
.714	1	.01
1.43	2	.04
2.14	3	.09
2.86	4	.16
3.57	5	.26
4.29	6	.37
5.00	7	.5



E9497

Fig. 6 Scanner Coordinates

When  $\gamma = \pi/2$ , the  $\hat{x}$  component of  $\hat{N}$  is negative. This represents a clockwise rotation when viewed facing in the same direction as the positive  $\hat{z}$  axis. The emerging ray is  $\hat{S}$ .

From the foregoing description

$$\hat{S}_o = -\sin \beta \hat{y} - \cos \beta \hat{z}$$

$$\hat{N} = -\sin \alpha \sin \gamma \hat{x} + \sin \alpha \cos \gamma \hat{y} + \cos \alpha \hat{z}$$

The component of  $\hat{S}_o$  normal to the mirror is  $(\hat{S}_o \cdot \hat{N})\hat{N}$  and the component tangential to the mirror is  $\hat{S}_o - (\hat{S}_o \cdot \hat{N})\hat{N}$ . Upon reflection, the normal component is reversed but the tangential component is not; therefore the emerging ray is

$$\hat{S} = \hat{S}_o - 2(\hat{S}_o \cdot \hat{N})\hat{N}$$

$$\hat{S}_o \cdot \hat{N} = -\sin \alpha \sin \beta \cos \gamma - \cos \alpha \cos \beta$$

The components of  $\hat{S}$  are

$$\begin{aligned} S_x &= -2 \sin \alpha \sin \gamma [\cos \alpha \cos \beta + \sin \alpha \sin \beta \cos \gamma] \\ &= -\sin 2\alpha \cos \beta \sin \gamma - \sin^2 \alpha \sin \beta \sin 2\gamma \end{aligned}$$

$$\begin{aligned} S_y &= -\sin \beta + 2 \sin \alpha \cos \gamma [\cos \alpha \cos \beta + \sin \alpha \sin \beta \cos \gamma] \\ &= -\sin \beta + \sin 2\alpha \cos \beta \cos \gamma + 2 \sin^2 \alpha \sin \beta \cos^2 \gamma \end{aligned}$$

$$\begin{aligned} S_z &= -\cos \beta + 2 \cos \alpha [\cos \alpha \cos \beta + \sin \alpha \sin \beta \cos \gamma] \\ &= -\cos \beta + 2 \cos^2 \alpha \cos \beta + \sin 2\alpha \sin \beta \cos \gamma \end{aligned}$$

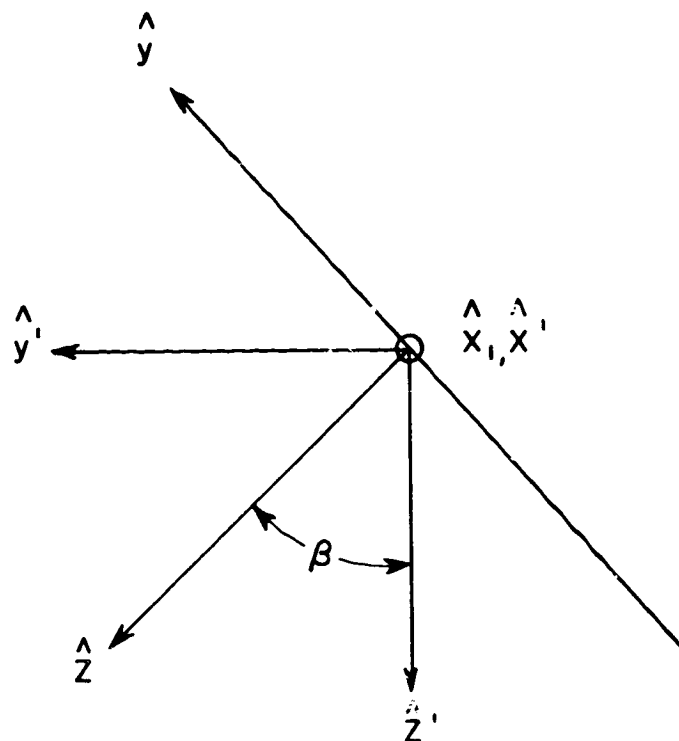
Next we transform to stationary aircraft coordinates  $\hat{x}'$ ,  $\hat{y}'$ ,  $\hat{z}'$  (see Fig. 7). We assume that  $\hat{x}'$ , the fore and aft axis of the aircraft is parallel to the scanner coordinate  $\hat{x}$ , and the aircraft vertical  $\hat{z}'$  is at an angle  $\beta'$  to the scanner coordinate  $\hat{z}$ .

The components of  $\hat{S}$  in aircraft coordinates are

$$S_{x'} = S_x$$

$$S_{y'} = S_y \cos \beta' + S_z \sin \beta'$$

$$S_{z'} = -S_y \sin \beta' + S_z \cos \beta'$$



E9495

Fig. 7 Transformation from Scanner to Aircraft Coordinates

Therefore

$$S_{x'}' = -\sin 2a \cos \beta \sin \gamma - \sin^2 a \sin \beta \sin 2\gamma$$

$$\begin{aligned} S_{y'}' &= -\sin \beta \cos \beta' + \sin 2a \cos \beta \cos \beta' \cos \gamma + 2\sin^2 a \sin \beta \cos \beta' \cos^2 \gamma \\ &\quad - \cos \beta \sin \beta' + 2\cos^2 a \cos \beta \sin \beta' + \sin 2a \sin \beta \sin \beta' \cos \gamma \\ &= -\sin(\beta' + \beta) + 2\cos^2 a \cos \beta \sin \beta' + \sin 2a \cos(\beta - \beta') \cos \gamma \\ &\quad + 2\sin^2 a \sin \beta \cos \beta' \cos^2 \gamma \end{aligned}$$

$$\begin{aligned} S_{z'}' &= \sin \beta \sin \beta' - \sin 2a \cos \beta \sin \beta' \cos \gamma - 2\sin^2 a \sin \beta \sin \beta' \cos^2 \gamma \\ &\quad - \cos \beta \cos \beta' + 2\cos^2 a \cos \beta \cos \beta' + \sin 2a \sin \beta \cos \beta' \cos \gamma \\ &= -\cos(\beta' + \beta) + 2\cos^2 a \cos \beta \cos \beta' + \sin 2a \sin(\beta - \beta') \cos \gamma \\ &\quad - 2\sin^2 a \sin \beta \sin \beta' \cos^2 \gamma \end{aligned}$$

For the special case  $\beta = \beta' = \pi/4$

$$S_{x'}' = -\frac{1}{\sqrt{2}} [\sin 2a \sin \gamma + \sin^2 a \sin 2\gamma]$$

$$\begin{aligned} S_{y'}' &= -1 + \cos^2 a + \sin 2a \cos \gamma + \sin^2 a \cos^2 \gamma = \sin 2a \cos \gamma \\ &\quad - \sin^2 a \sin^2 \gamma \end{aligned}$$

$$S_{z'}' = \cos^2 a - \sin^2 a \cos^2 \gamma$$

The intersections of the ray  $\hat{S}$  with the ground from an aircraft with no pitch or roll, flying in the  $+\hat{x}'$  direction with speed  $s$  and altitude  $h$ , maintaining  $\hat{z}'$  parallel to the vertical is

$$v_{x'} = s t + h \frac{S_{x'}'}{S_{z'}'}; \quad v_{y'} = h \frac{S_{y'}'}{S_{z'}'}; \quad \gamma = 2\pi f t \quad (11)$$

$v_{x'}$  and  $v_{y'}$  are the coordinates of the intersection with the ground and  $f$  is the rotation rate of the scanner,  $t$  is time.

For the special case  $\beta' = \beta = \pi/4$ , the equations reduce to

$$\frac{S_{x'}'}{S_{z'}'} = -\sqrt{2} \frac{\sin \gamma}{\cot a - \cos \gamma} \quad \frac{S_{y'}'}{S_{z'}'} = \frac{2 \cot a \cos \gamma - \sin^2 \gamma}{\cot^2 a - \cos^2 \gamma}$$

In the limit of small  $a$

$$\frac{S'_x}{S'_z} \cong -\sqrt{2} \tan \alpha \sin \gamma \cong -\sqrt{2} \alpha \sin \gamma$$

$$\frac{S'_y}{S'_z} \cong 2 \tan \alpha \cos \gamma \cong 2 \alpha \cos \gamma$$

These are the equations of an ellipse with semi-major axis =  $2\alpha$  and semi-minor axis =  $\sqrt{2} \alpha$ .

The interlace condition is similar to the circular scan case except for  $f = p s/W'$  where

$$W' = h \frac{S'_x}{S'_z} \left( \gamma = \frac{\pi}{2} \right) = -\sqrt{2} h \tan \alpha.$$

For a moving aircraft we would like to include the pitch angle,  $\theta$  and roll angle  $\phi$ . To include  $\phi$ , replace  $\beta'$  by  $\beta'_0 = \phi$  where  $\beta'_0$  is the angle between the scanner axis and the aircraft axis. To include  $\theta$  in the small angle approximation, we use the transformation

$$S''_x = S'_x \cos \theta + S'_z \sin \theta$$

$$S''_y = S'_y$$

$$S''_z = -S'_x \sin \theta + S'_z \cos \theta$$

and replace  $S'$  by  $S''$  in the equations for  $v_{x'}$  and  $v_{y'}$  (see Eq. (11)).

#### B. Catalog of Scanning Patterns

Using Eq. (11), we have computed the scan pattern for a number of different changes in the parameters. Fig. 8 shows the pattern under the reference conditions 609 m (2000 ft) altitude, a speed of 76 m/sec (150 kts), a scan angle of  $5^\circ$ , a laser pulse repetition frequency of 400 pps and a scanning mirror rotation rate of 5.06 cycles per second. This rotation rate is arrived at from the condition for good interlace. Figure 9 shows the same conditions except that now the scan angle is  $10^\circ$  and Fig. 10 is for a scan angle of  $15^\circ$ . Figure 11 is for the same conditions as in Fig. 8 except that the aircraft altitude has been decreased to 152 m (500 ft). Figure 12 is the pattern at an altitude of 152 m, except that the velocity has been increased to 126 m/sec (250 kts). Figures 13 and 14 are plots of the patterns for the same conditions as Fig. 8, except that the scanner



$H = 609 \text{ m}$   
 $S = 76 \text{ m/sec}$   
 $2\alpha = 5.00 \text{ DEG}$   
 $1/\Delta = 400 \text{ PPS}$   
 $F = 5.06 \text{ CPS}$

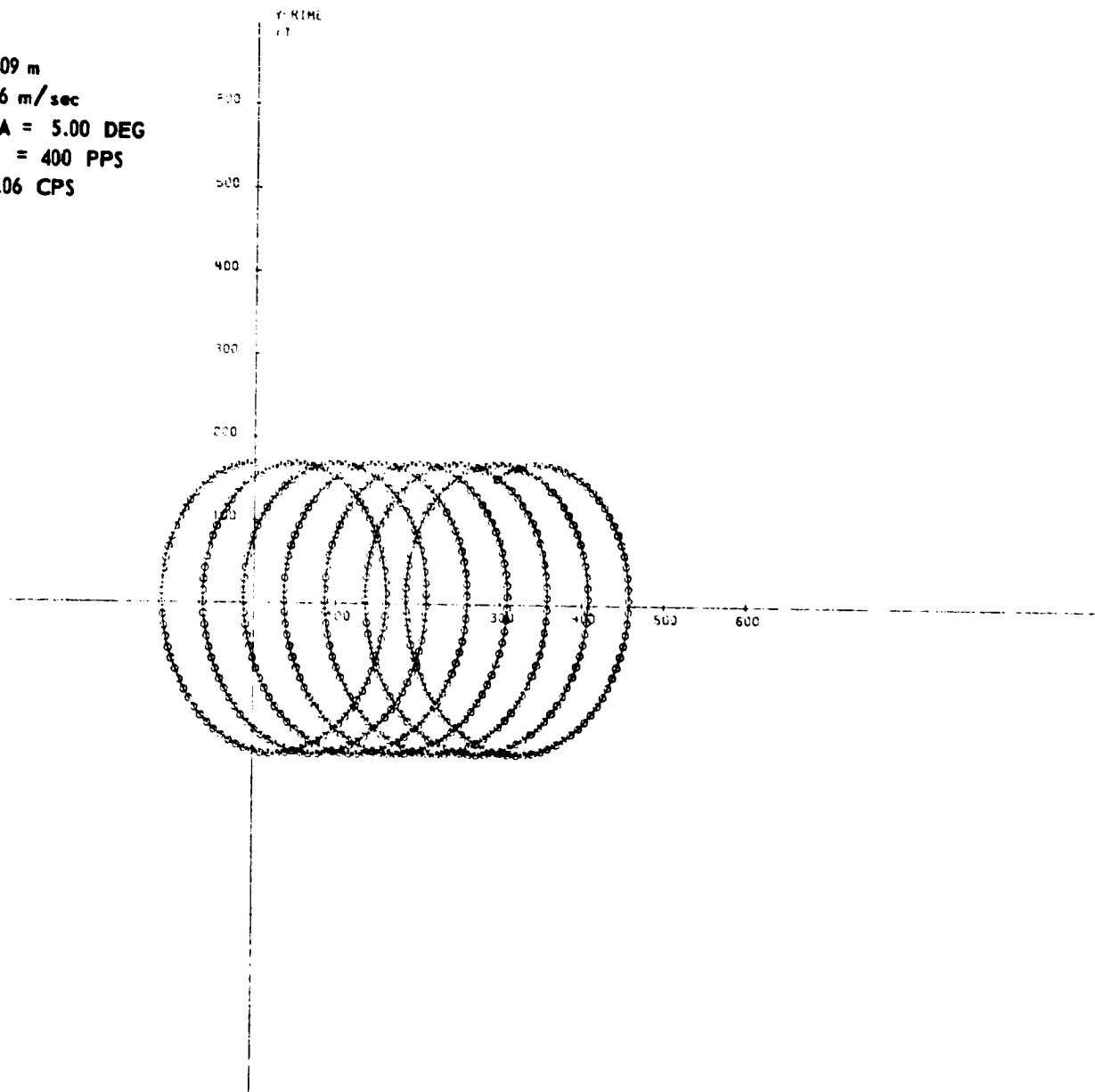


Fig. 8 Scanning Pattern for Conditions Shown

$H = 609 \text{ m}$   
 $S = 76 \text{ m/sec}$   
 $2\alpha = 10.00 \text{ DEG}$   
 $1/\Delta = 400 \text{ PPS}$   
 $F = 5.06 \text{ CPS}$

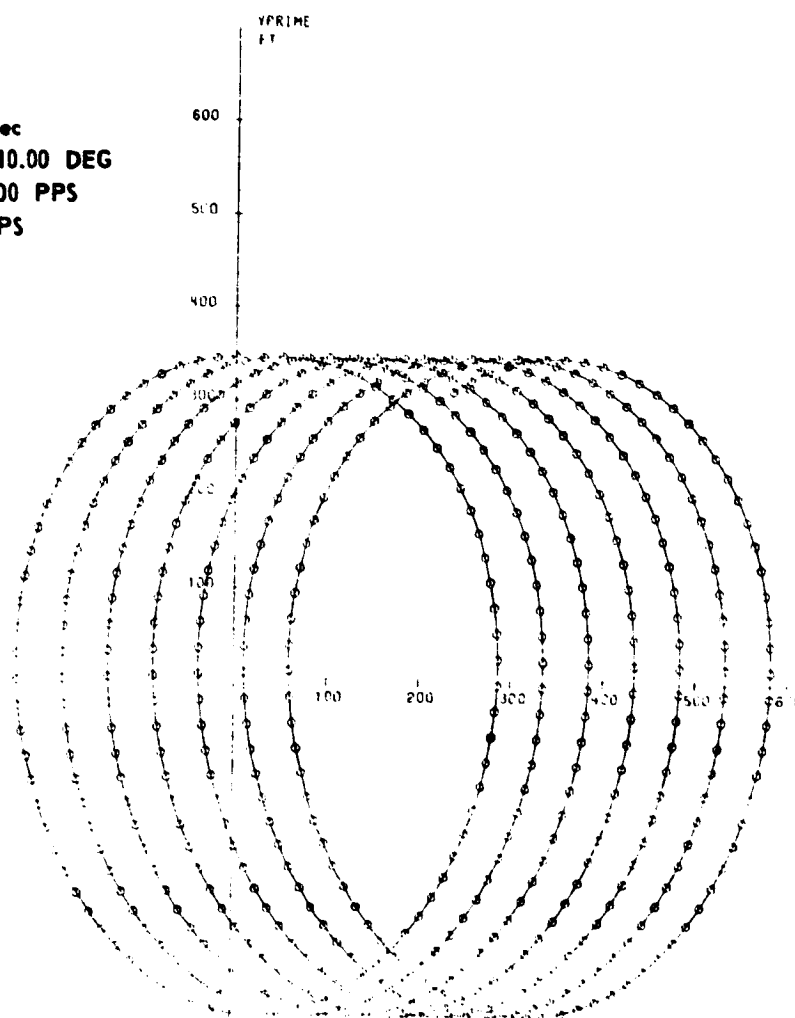


Fig. 9 Scanning Pattern for Conditions Shown

$H = 609 \text{ m}$   
 $S = 76 \text{ m/sec}$   
 $2\text{ALPHA} = 15.00 \text{ DEG}$   
 $1/\text{DEL} = 400 \text{ PPS}$   
 $F = 5.06 \text{ CPS}$

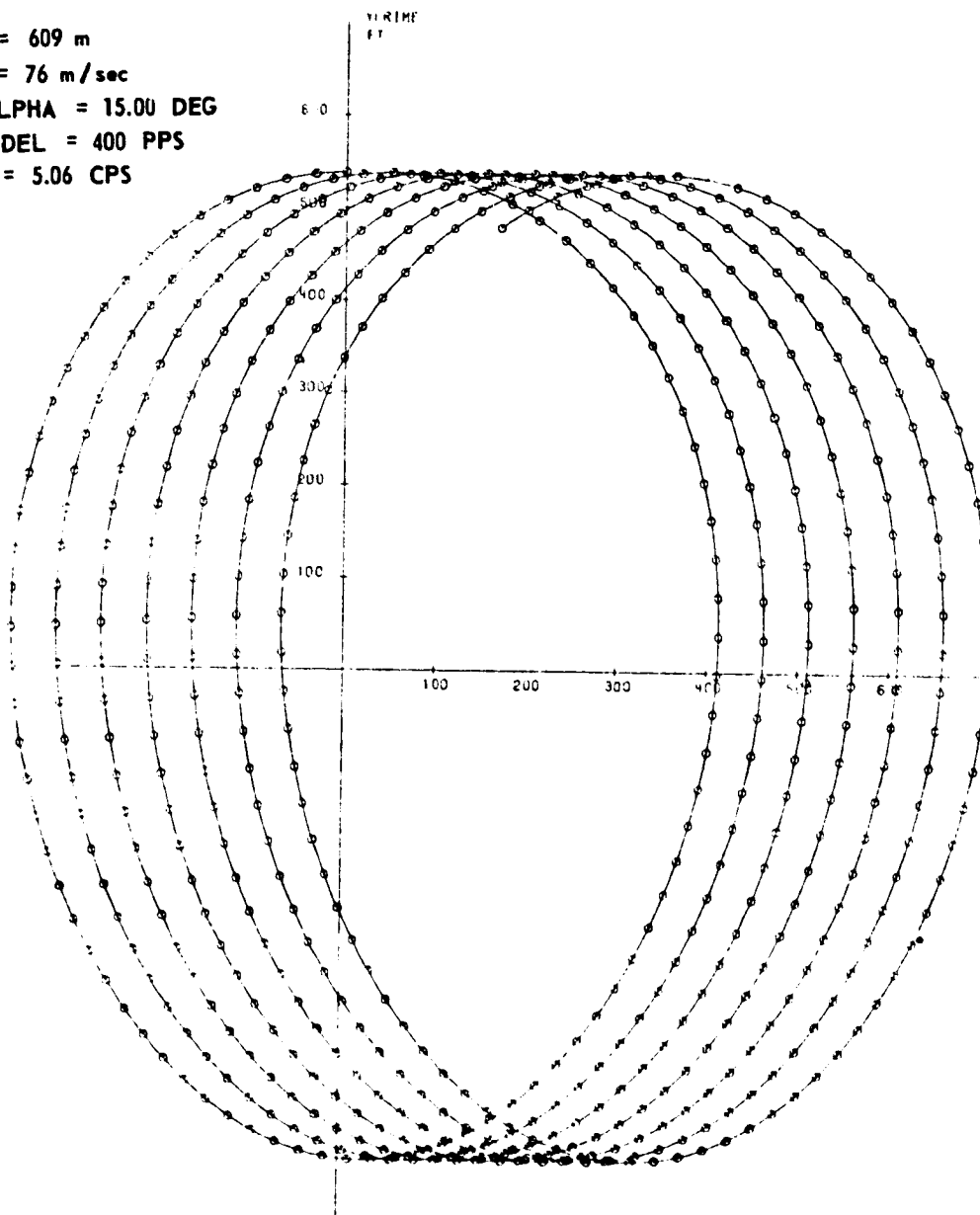


Fig. 10 Scanning Pattern for Conditions Shown

$H = 152 \text{ m}$   
 $S = 76 \text{ m/sec}$   
 $2\text{ALPHA} = 5.00 \text{ DEG}$   
 $1/\text{DEL} = 400 \text{ PPS}$   
 $F = 5.06 \text{ CPS}$

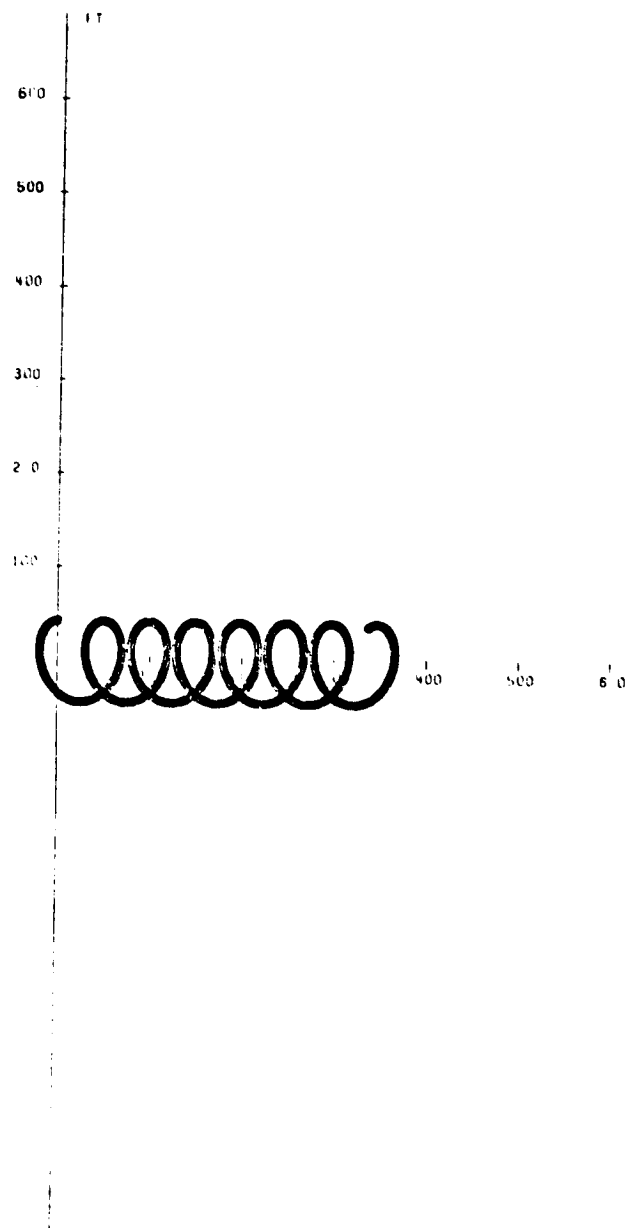


Fig. 11 Scanning Pattern for Conditions Shown

H = 609 m  
S = 126 m/sec  
2ALPHA = 5.00 DEG  
1/DEL = 400 PPS  
F = 5.06 CPS

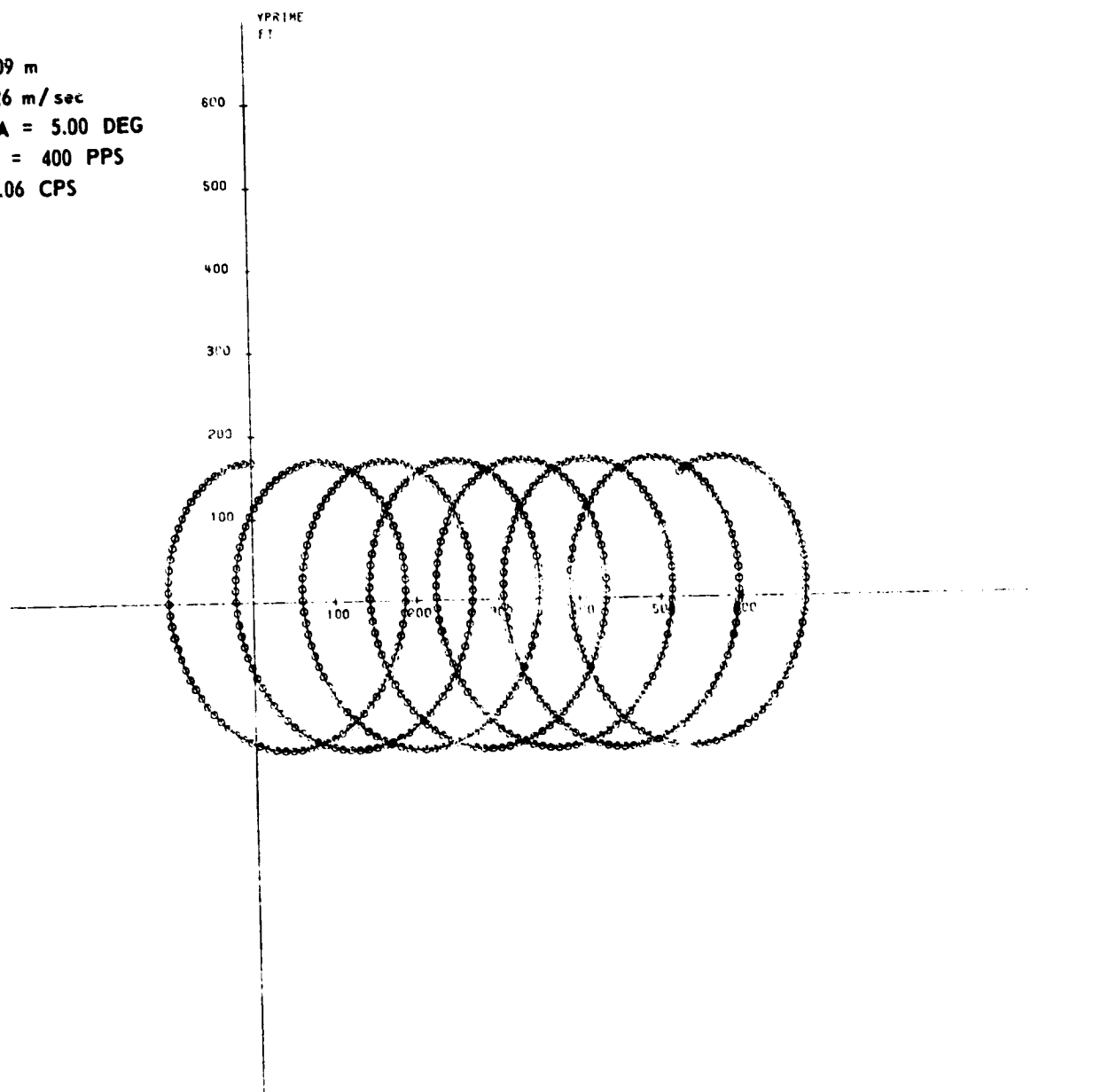


Fig. 12 Scanning Pattern for Conditions Shown

$H = 609 \text{ m}$   
 $S = 76 \text{ m/sec}$   
 $2\text{ALPHA} = 5.00 \text{ DEG}$   
 $1/\text{DEL} = 400 \text{ PPS}$   
 $F = 3.00 \text{ CPS}$

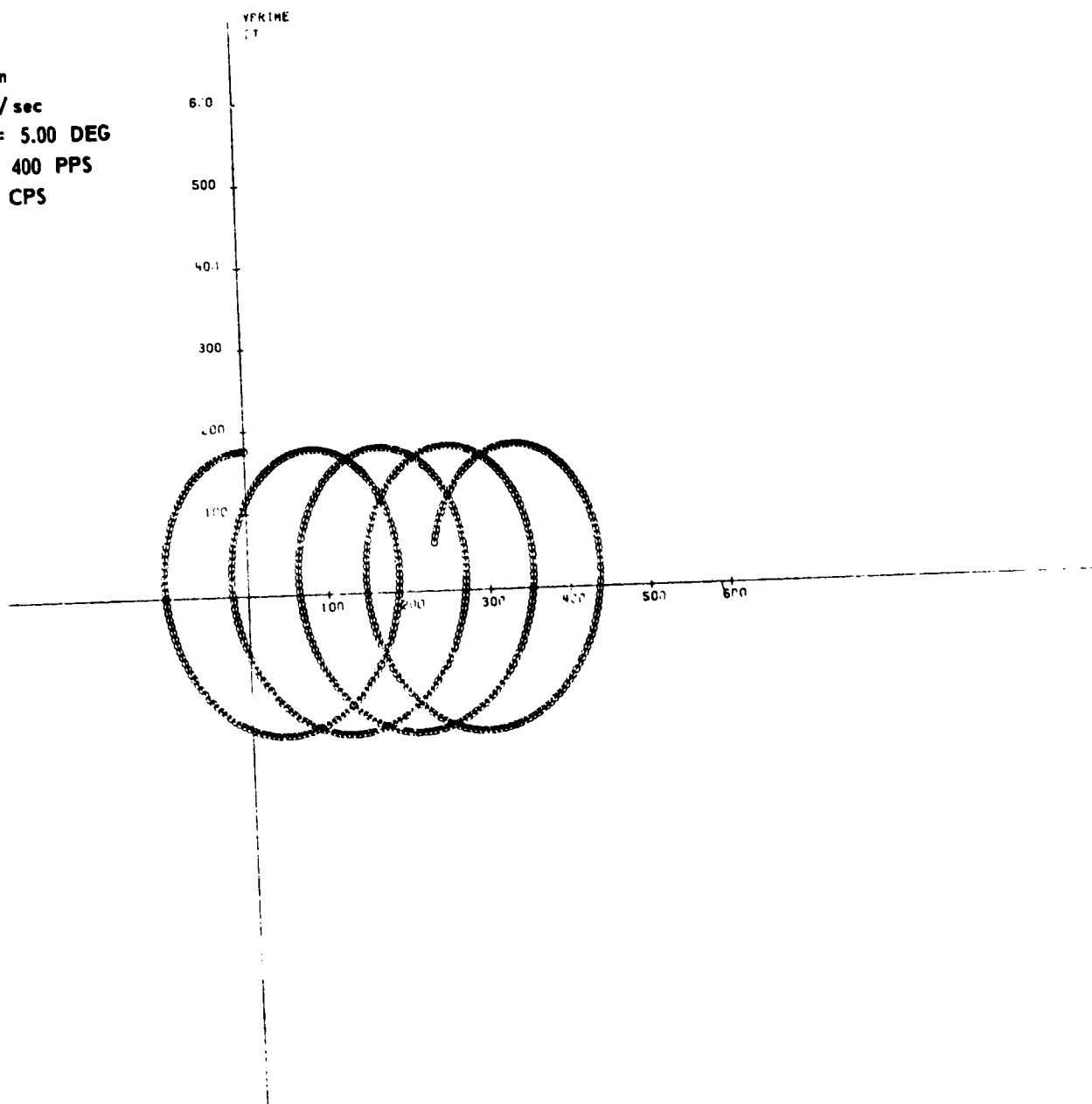


Fig. 13 Scanning Pattern for Conditions Shown

H = 609 m  
S = 76 m/sec  
2ALPHA = 5.00 DEG  
1/DEL = 400 PPS  
F = 1.00 CPS

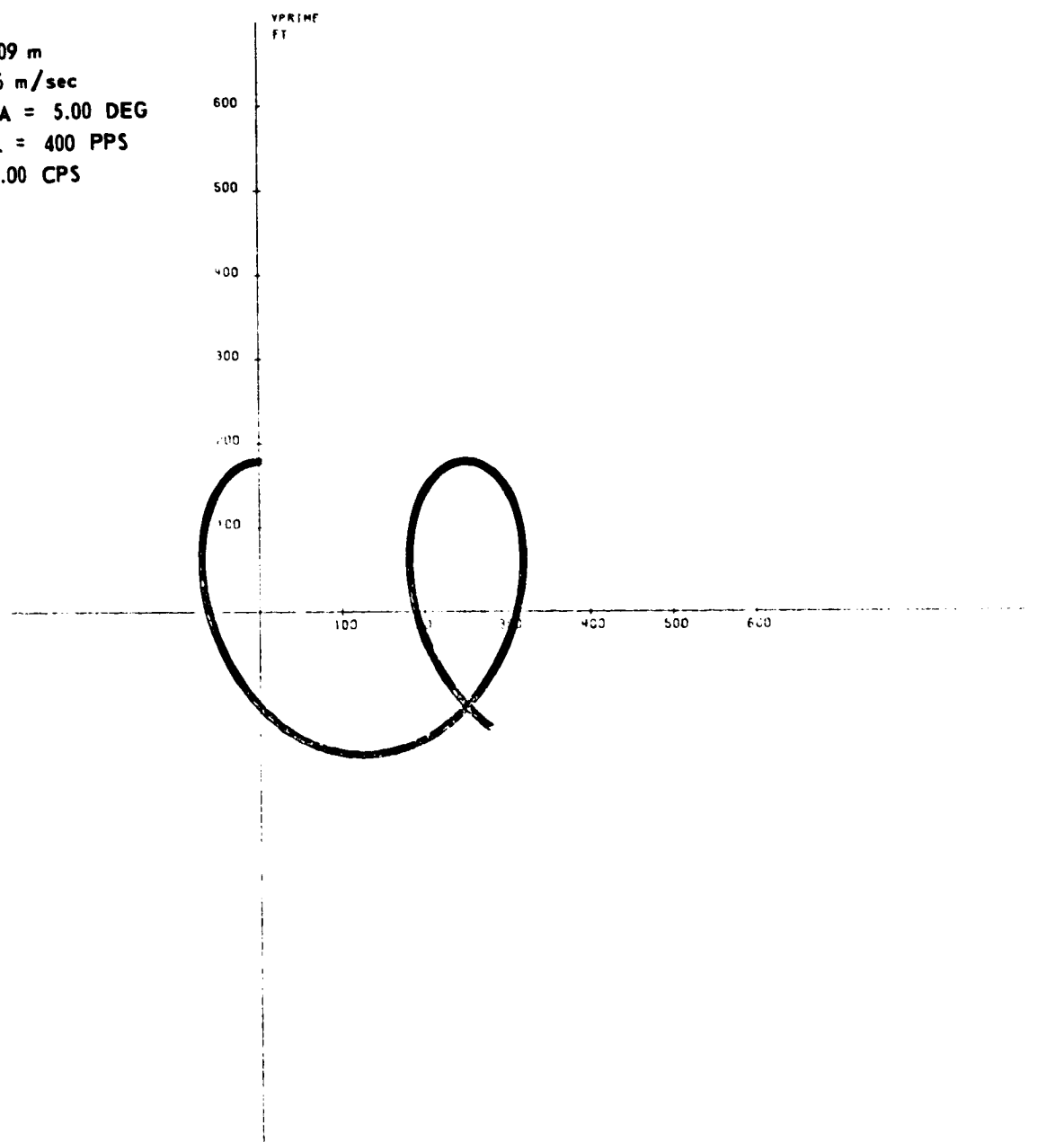


Fig. 14 Scanning Pattern for Conditions Shown

rotation rate has been slowed to 3 cps and 1 cps, respectively. This set of figures shows how the scanning pattern changes with changes in the various parameters.



## SECTION V

### SYSTEM SPECIFICATIONS

#### 1.0 INTRODUCTION

This section presents the specifications for the design and fabrication of the AOL. The reader is referred to other sections of this report, principally Section VI, for the tradeoffs and analyses attendant to the development of these specifications.

#### 2.0 OPTICAL (SENSING) SYSTEM

The specifications for the various components in the AOL optical system (see Fig. 1), are as follows:

##### 2.1 Transmitter

The components required in the transmitter subsystem are:

- a) A laser with its ancillary units.
- b) A linear polarizer which can be installed during bathymetry operation to improve the polarization of the laser beam.
- c) A beam expander for controlling the divergence of the laser beam.
- d) A folding flat to direct the laser beam into the scanner assembly, with adjustments for aligning the beam to a datum.

##### 2.1.1 Laser

The characteristics of the laser required to satisfy the fluoro-sensing and bathymetry requirements stated in Section II are as follows:

##### A. Bathymetry

- Excitation Wavelength:  $5400 \text{ \AA}$   
Excitation Bandwidth:  $\leq 1 \text{ \AA}$   
Pulse Repetition Rate:  $\geq 400 \text{ pps}$   
Excitation Pulse Width:  $\leq 4 \text{ nsec}$   
Beam Divergence:  $\leq 2 \text{ mr}$  with 2 x beam expander

Peak Power:

The maximum available in a unit whose dimensions and operating characteristics are commensurate with the above requirements and the space constraints delineated in Section VI

B. Fluorosensing Laser

Excitation Wavelength: 3371 - 6600 Å, variable with dye

Excitation Bandwidth: 1 Å at 3371 Å, 7-10 Å with dye

Pulse Repetition Rate:  $\leq 100$  pps

Excitation Pulse Width:  $\leq 8$  nsec

Beam Divergence: 2 mr with 2 x beam expander

Peak Power:

The maximum available in a unit whose dimensions and operating characteristics are commensurate with the above requirements and the space constraints delineated in Section VI

2.1.2 Laser Mirrors

For use with a laser/dye module combination, two folding mirrors are required of the following description:

Size: 75 mm x 25 mm, minimum

Flatness:  $1 \lambda$

Nominal Reflectivity: 98%, peaked for 3371 and 5400 Å

Substrate: Glass, 2.5 mm thick, minimum

Mounting Provision: Right-angle mount, with mirror located on vertical leg, at a height of approximately 15 cm above the horizontal surface

2.1.3 Polarizer

The housing for the transmitting optics is to include provisions for installing a polarizer when needed. The unit is to be removable without upsetting the pointing axis of the transmitter. A linear polarizer is required, having good transmission at the 5400 Å wavelength used for bathymetry. of the following description:

Size:	50 mm dia. minimum clear aperture
Nominal Transmission:	$\geq 35\%$ at $5400 \text{ \AA}$
Mounting Provision:	Holder attached to transmitting optics housing

#### 2.1.4 Beam Expander

A beam expander is required to increase the beam size by 2 x. The optics required are a negative input and a positive output lens. The focal lengths and spacing are to be chosen to fit within the specified space allocation, and one element is required to be movable to permit manual adjustment of the beam divergence. Its characteristics are:

Entrance Aperture:	50 mm, minimum
Exit Aperture:	100 mm, minimum
Divergence Adjustment Range:	1 to 20 mr
Lens Material:	Fused silica, AR coated
Nominal Transmission:	Not less than 90% over the spectral region of $3370 - 6600 \text{ \AA}$

#### 2.1.5 Transmitting Folding Flat

A diagonal mirror is required to direct the laser beam downward to the scanner. The mirror is to be of adequate size to accommodate the 100 mm beam from the beam expander. Pointing adjustments are to be included for aligning the transmitted beam to the axis of the receiver. Its characteristics are:

Mirror Size:	150 mm x 120 mm, minimum
Flatness:	$1 \lambda$
Material:	Glass or pyrex, aluminized and overcoated
Reflectivity:	84% minimum at $3370 \text{ \AA}$ 88% minimum at $5400 \text{ \AA}$ 86% minimum at $6700 \text{ \AA}$
Mounting Provision:	The mirror surface is to be tilted downward at $45^\circ$ with adjustments for varying the mirror attitude about

two orthogonal axes parallel to the mirror surface. The range of adjustment is to be  $\pm 10$  mr and the stability of the adjustment  $\pm 0.1$  mr.

## 2.2 Receiver

### 2.2.1 Receiver Folding Flat

A lightweight diagonal mirror is required to direct the incoming light from the scanner into the receiver. The mirror must be of adequate size to cover the entrance aperture of the telescope, with a center hole to transmit the outgoing laser beam. Pointing adjustments are required for aligning the receiver axis to an external datum. Its characteristics are:

Mirror Size:	320 mm x 450 mm clear aperture
Center Hole:	115 mm dia. hole at $45^\circ$ to the mirror surface
Flatness:	$1\frac{1}{2}\lambda$ maximum power $1/2\lambda$ irregularity
Material:	Aluminum, electro-less nickel coated, aluminized, and overcoated
Reflectivity:	84% minimum at $3500\text{ \AA}$ 88% minimum at $5400\text{ \AA}$ 86% minimum at $8000\text{ \AA}$
Scratch and Dig:	60 - 40
Mounting Provision:	The mirror surface is to be tilted downward at $45^\circ$ with adjustments for varying the mirror attitude about two orthogonal axes parallel to the mirror surface. The range of adjustment is to be $\pm 10$ mr and the stability of the adjustment $\pm 0.1$ mr.

### 2.2.2 Telescope

The collector for the system shall be a cassegranian type telescope with fixed focus having the following characteristics:

Entrance Aperture:	305 mm diameter
Focal Length:	1220 mm

Relative Aperture:	f/4
Center Obscuration:	120 mm
Mirrors:	Glass or pyrex, aluminized and over-coated for a minimum reflectivity of 84% at 3500 Å, 88% at 5400 Å, and 86 % at 8000 Å
Image Quality:	90% of the light in the image of a point source will fall within a diameter of 250 microns in the focal plane
Baffles:	Light from outside the telescope field-of-view will be prevented from entering the telescope aperture and traveling directly to the field stop. Baffles for this purpose will be incrementally adjustable for fields-of-view between 2 and 20 mr.

#### 2.2.3 Field Stop

The receiver field-of-view will be limited by a rectangular field stop with independently adjustable width and height settings. Remote controls for this purpose are required. Its characteristics are:

Field-of-View:	0-20 mr, vertical and horizontal
Aperture Size:	0-25 mm, vertical and horizontal

#### 2.2.4 Polarizer

A linear polarizer is required for controlling the transmission of the polarized bathymetry return beam. Its characteristics are:

Size:	100 mm diameter clear aperture
Nominal Transmission:	≥ 35% at 5400 Å
Mounting Provision:	Removable, and capable of being rotated through 90°

#### 2.2.5 Collimator Folding Flat

A diagonal mirror is required to fold the optical path towards the detector assemblies so as to maintain a compact system configuration. A center hole in the mirror is needed to provide an optical path for a detector check lamp. Its characteristics are:

Mirror Size:

Center Hole:

Flatness:

Material:

90 mm diameter clear aperture  
10 mm maximum diameter at 45° to  
mirror surface

1  $\lambda$

Glass or pyrex, aluminized and over-  
coated for a minimum reflectivity of:  
84% at 3500 Å, 88% at 5400 Å, and  
86% at 8000 Å

#### 2.2.6 Collimating Lens

A lens of the following description is required for collimating the  
light which passes through the field stop. Its characteristics are:

Focal Length:

Effective Aperture:

Material:

Transmission:

400 mm

100 mm diameter, f/4

Fused silica, AR coated

Not less than 95% over the spectral  
region of 3500 - 8000 Å

#### 2.2.7 Flip Mirror

A removable mirror is required which, when installed, will reflect  
the collimated beam to the spectrometer and when removed, will allow the  
collimated beam to pass directly to the bathymetry detector. A small hole  
in the mirror is required to allow a portion of the light to pass through  
for surface return detection. Mirror characteristics are:

Mirror Size:

Center Hole:

Flatness:

Material:

Mounting Provision:

190 mm x 120 mm minimum clear  
aperture

10 mm maximum diameter at 45° to  
mirror surface and offset from the  
center obstruction

1  $\lambda$

Glass or pyrex, aluminized and over-  
coated for a minimum reflectivity of  
84% at 3500 Å, 88% at 5400 Å, and  
86% at 8000 Å

Removable, without affecting receiver  
alignment

### 2.3 Bathymetry and Surface Return Detection Assembly

For bathymetry, the components shown in Fig. 1 are all required except the flip mirror. For fluorosensing, the same units are used for providing surface return detection, except that a different spectral filter is required, and the effective aperture of the optical train is limited by the size of the hole in the flip mirror.

#### 2.3.1 Bathymetry Filter

A narrow band spectral filter is required for use in bathymetry. The filter is replaceable so that the detector can also operate at a different wavelength as a surface return detector. Its characteristics are:

Spectral Bandpass	4 Å
(1/2 power):	
Center Wavelength:	5400 Å
Nominal Transmission at	40% minimum
Center Wavelength:	
Size:	120 mm clear aperture
Mounting Provision:	Slide mounted for ease of replacement

#### 2.3.2 Surface Return Filter

A relatively broad band spectral filter is required for use with the bathymetry detector during fluorosensing. The center wavelength would match that of the laser. The filter would be interchangeable with the bathymetry filter. Its characteristics are:

Spectral Bandpass	≈ 1000 Å
(1/2 power):	
Center Wavelength:	Match to laser wavelength for the particular experiment
Nominal Transmission:	≥ 50% minimum
Size:	120 mm clear aperture, maximum
Mounting Provision:	Slide mounted for ease of replacement

#### 2.3.3 Bathymetry Lens

A lens of the following description is required to converge the collimated beam onto the face of the photomultiplier detector:

Focal Length:	200 mm
Effective Aperture:	100 mm diameter, f/2

Material:	Optical crown glass, AR coated
Transmission:	95% minimum at 5400 Å

#### 2.3.4 Neutral Density Filters

A selection of neutral density filters is required to ensure that the photomultiplier is always operated in its linear range. The filters are to be mounted in interchangeable holders with convenient access provided for manual insertion and removal. Their characteristics are:

Density Values:	2 and 4
Size:	100 mm diameter clear aperture

#### 2.3.5 Bathymetry and Surface Return Detector

A photomultiplier tube will be required for bathymetry and surface return signal detection. Its characteristics are:

Quantum Efficiency at 5400 Å:	$\geq 7.6\%$
Gain:	$\geq 1 \times 10^6$
Rise Time:	$\leq 2 \text{ nsec}$
Dark Noise:	$\leq 1 \times 10^{-7} \text{ amp}$
Maximum Anode Current:	$0.1 \times 10^{-3} \text{ amp avg.}$
Size:	5.08 cm dia. (2 in.) x $\leq 14.6 \text{ cm}$ long (5.75 in.)

#### 2.4 Fluorosensing Detection Assembly

The elements required for fluorosensing are: a diffraction grating, an imaging lens, a filter to block the second order spectrum, a light guide array to transmit light from the spectral image to each of the multichannel photomultiplier detectors, and the detectors themselves. The specifications for these components are as follows:

##### 2.4.1 Spectrometer Grating

Type:	Transmission
Ruled Spacing:	600 gr/mm
Blaze Wavelength:	4800 Å
Spectral Range:	3500 - 8000 Å
Nominal Transmission:	60% at blaze wavelength, 30% at 3500 Å, and 34% at 8000 Å



#### 2.4.2 Spectrometer Lens

Focal Length:	400 mm
Effective Aperture:	100 mm diameter, f/4
Material:	Fused silica, AR coated
Transmission:	Not less than 95% over the spectral region of 3500 - 8000 Å

#### 2.4.3 Blocking Filter

A small filter is required in front of the spectral image plane, covering the spectral region of 6500 - 8000 Å. The filter will transmit the 6500 - 8000 Å region and block the second order spectrum of 4000 Å and below.

Type:	Colored glass, AR coated
Nominal Transmission:	95% min at 6500 - 8000 Å, less than 0.01% at 4000 Å and below

#### 2.4.4 Light Guides

An array of forty light guides is required to transmit the light from the spectral image to the photomultiplier detectors. Each light guide is to have a face area of 2.7 mm x 7.2 mm. The light guides are to be bonded together on the broad surfaces so that the final assembly covers an image space of 112 mm x 7.2 mm. The unbonded ends of the light guides are to fan out to a grid pattern of five horizontal rows of detectors with eight detectors in each row. The end of each light guide is to be fitted with an adapter to mate with the face of the PM tube. The nominal transmission of the light guide is 60% at peak wavelength which includes a 30% end loss and a 10% transmission loss. The area of the cladding material on each guide is approximately 20% of the face area, which reduces the effective width of each guide to 2.3 mm.

#### 2.4.5 Fluorosensing Multi-Channel Detectors

Forty photomultiplier tubes will be required for fluorescence signal detection. Their characteristics are:

Quantum Efficiency (3500 - 8000 Å):	Maximum possible over range
Gain:	$\geq 7 \times 10^5$
Rise Time:	$\leq 3$ nsec

Dark Noise:	$\leq 1 \times 10^{-7}$ amp
Maximum Anode Current:	$\geq 0.1 \times 10^{-3}$ amp avg.
Size:	$\leq 1.9$ cm dia. (0.75 in.) x 10 cm long (4 in.)

## 2.5 Scanning Assembly

The components required in the scanning assembly are: a fixed folding flat, a rotating flat (scanning mirror), its drive motor, and a platform to support all of the components and to supply an interface with the underside of the optical platform. The entire assembly is to be of lightweight construction to facilitate installation and removal through the aircraft cargo hatch.

The rotation axis of the scanning mirror is to be positioned at  $45^\circ$  as shown in Fig. 1, and the mirror surface is initially perpendicular to the rotation axis so as to direct the laser beam into a vertical path. Provisions are required for incrementally setting the mirror surface to various angles so as to produce a selection of scanning angles up to  $15^\circ$  from the vertical.

The scanning rate is to be fixed at 5 rev/sec, and the rotational position of the mirror is to be sensed to 14 bit encoder accuracy and recorded. The specifications for the mirrors are:

Size of Scanning Flat:	560 mm diameter
Size of Fixed Flat:	480 x 330 mm
Flatness:	$1 \frac{1}{2} \lambda$ maximum power, $1 \frac{1}{2} \lambda$ irregularity
Material:	Aluminum, electro-less nickel coated, aluminized, and overcoated
Reflectivity:	84% minimum at 3500 Å, 88% minimum at 5400 Å, and 86% minimum at 8000 Å
Scratch and Dig:	60 - 40

## 2.6 Optical Platform

An optical platform is required to provide a stable mounting surface for all transmitter and receiver components including a suitable surface for rigidly interfacing with the scanner assembly. The structure is to be of lightweight construction to facilitate installation and removal, but of adequate stiffness to maintain alignment between optical components. Isolators are to

be provided between the platform and the aircraft floor interface. Adequate strength will be provided in the structure and in the interconnections with the various components to comply with the specified design loads.

## 2.7 Optical System Alignment

The primary requirements in aligning the optical system are:

- a) Alignment of the receiver components to a common optical axis within the receiver
- b) Alignment of the receiver axis to a vertical reference which can be correlated with the inertial navigation system
- c) Alignment of the transmitter to the receiver axis

The specifications for meeting these requirements are discussed below:

### 2.7.1 Receiver Axis

The establishment of a receiver axis is important for initial alignment of the receiver components and also for assessment of stability in the aircraft environment. The receiver axis will be defined as a line passing through the centers of the telescope field stop and entrance aperture. (A collimated beam projected parallel to this line into the telescope will come to a focus at the center of the field stop.) The optical train of the bathymetry detector and the spectrometer must be aligned initially with this axis and must remain stable to a degree which will assure no loss of signal under normal operating conditions. In terms of the optical units, this means that the optical axis of each subassembly must not be deflected more than a small fraction of the field-of-view. For a field-of-view of 3 mr, an allowance of 10% or 0.3 mr is considered permissible for initial alignment. Finally, the optical platform should have adequate stiffness to meet this requirement when subjected to aircraft vibration.

### 2.7.2 Alignment of Receiver to a Vertical Reference

In order to relate the bathymetry return signal to a point of accurately known terrestrial coordinates, it is necessary to set the scanner axis to a datum position and align the receiver to a vertical reference on the aircraft. The vertical reference could be the inertial navigator or some reference which is correlatable to the inertial navigator. The adjustments for aligning the receiver to the chosen reference should have an accuracy and stability of 0.3 mr.

### 2.7.3 Alignment of Transmitter to Receiver

Misalignment of the transmitter to the receiver will result in a loss of signal or a reduced signal-to-noise ratio. For the reasons previously discussed, an alignment tolerance of 0.3 mr is considered satisfactory. The adjustments for pointing the transmitter will be chosen for achieving this accuracy, initially, and retaining it under operating conditions. Also, the optical platform should have adequate stiffness to meet this requirement.

### 2.7.4 Optical Alignment Equipment

Since the AOL will be removed and reinstalled in the aircraft periodically, it is likely that routine alignment checks will be performed, and that special purpose equipment will be needed to perform these checks. The essential items for this purpose are:

- a) An alignment microscope for viewing the focal plane of the receiver
- b) A diagonal mirror for deflecting the vertically transmitted beam into a horizontal path over to screen at some distance from the aircraft
- c) A theodolite for simulating a return beam at a known angle

The specifications for these units are:

#### 2.7.4.1 Alignment Viewer

Object Distance:	Up to 200 mm
Object Size:	25 mm
Focus Adjustment:	Rack and pinion
Mounting Provision:	Special adapter to install in place of the folding flat inside the receiving collimating optics housing

#### 2.7.4.2 Alignment Diagonal Mirror

The alignment mirror surface must be tilted upward at  $45^{\circ}$  from the bottom of its mount. The mount, therefore, is to be equipped with adjustments for pointing the mirror in azimuth and elevation.

In order that the mirror will be of satisfactory quality for use in both alignment and calibration, it must have the following specifications:

Mirror Size:	450 mm diameter
Flatness:	$1/4 \lambda$
Adjustment Range:	$10^{\circ}$ in elevation and azimuth

#### 2.7.4.3 Alignment Theodolite

The function of the alignment theodolite is to provide a projected beam which can be pointed at a known angle related to terrestrial coordinates. The unit must have the capability for aligning to True North bench marks and then swinging to a measured pointing axis which coincides with the AOL receiver axis. The unit therefore must have the following specifications:

Effective Aperture:	25 mm
Resolution:	4 arc sec
Focus:	30 m to infinity
Field-of-View:	1° minimum
Measuring Accuracy:	20 arc sec direct reading
Bubble Sensitivity:	20 arc sec per division
Mounting Provision:	Tripod

#### 2.8 Optical System Calibration

The response of the AOL to a source of known intensity can be periodically calibrated by means of two different types of calibrators. One is a portable calibration unit which can be easily set up at a measured distance from the aircraft. The other is a collimated calibration system which can be set up in the aircraft by removing the receiver folding flat and projecting the collimated beam directly into the receiver telescope. Or if preferred, the collimator can be set up under the aircraft with the collimated beam pointing upward along the scanner axis.

##### 2.8.1 Portable Calibration Unit

The specifications for one commercially available unit which is representative of the required unit are as follows:

Source:	45 W tungsten-halogen lamp with irradiance calibration traceable to NBS
Maximum Lamp Irradiance at 1000 nm:	$1 \mu\text{W}/\text{cm}^2 - \text{nm}$
Uncertainty of Irradiance:	$\pm 1.5\%$
Size of Lamp Enclosure:	15 cm x 15 cm x 30 cm
Power Supply:	Constant current supply operable from 115 V, 60 Hz line

Maximum Lamp Current      6.5 amps

Output:

Output Current Accuracy:     $\pm 0.1\%$

#### 2.8.2 Collimated Calibration Unit

This unit is comprised of a collimator which contains collimating optics, a pinhole aperture, imaging optics, neutral density filters, a tungsten ribbon filament lamp with a calibration traceable to NBS and a constant current power supply for controlling lamp current. Its specifications are as follows:

Collimating Optics:	Same as for the telescope specified in para. 2.2.2 except that no baffles are required
Lamp Type:	GE 30A/T24/3
Lamp Current:	35 amp
Lamp Calibration	4% in the visible, 9% in the UV
Uncertainty:	
Power Supply:	Constant current supply operable from 115 V, 60 Hz line, with an output current accuracy of $\pm 0.1\%$

#### 2.9 Footprint Camera

A wide angle cine camera of the following specifications is required for acquiring ground truth data during daylight missions:

Format:	Double Frame 35 (24 x 36 mm)
Shutter Opening:	90°
Framing Rate:	10, 20, and 30 frames/sec
Correlation Pulse:	Set at midpoint of shutter opening
Motor:	110 V, 60 Hz
Timing Lights:	LED
Film Capacity:	35 mm x 122 m magazine load
Lens:	50 mm F. L. , f/1.4
Field-of-View:	27° x 40°

#### 3.0 ELECTRONIC SYSTEM

The specifications for the various components in the AOL electronics system (see Fig. 2), are as follows:

### 3.1 Control and Data Acquisition Subsystem

#### 3.1.1 Altitude Intervalometer

An altitude intervalometer is required to measure aircraft altitude on a per pulse basis. Its characteristics are:

Altitude Range:	152 m to 609 m
Range Accuracy:	$\pm 0.5$ m
Measurement Resolution:	$\pm 0.25$ m
Output:	16 bit binary (TTL compatible)

#### 3.1.2 Data Acquisition Unit

##### 3.1.2.1 Bathymetry

The characteristics of the data acquisition unit required to satisfy the bathymetry application are as follows:

Impedance:	50 $\Omega$
Bandwidth:	DC to > 200 MHz
Range:	0 to -1.25 V
Overload Recovery:	$\leq 20$ nsec for 10 V input
Resolution:	1 part in 300
Differential Nonlinearity:	$\pm 2.0\%$ from 5 to 100% full scale at 3 nsec gate width
Sensitivity:	0.25 pico coulombs
Conversion Time:	< 50 $\mu$ sec
Gate Rise and Fall Time:	< 1 nsec
Gate Width:	< 3 nsec

##### 3.1.2.2 Fluorosensing

The characteristics of the data acquisition unit required to satisfy the fluorosensing application are as follows:

Impedance:	50 $\Omega$
Bandwidth:	$\geq 175$ MHz
Overload Recovery:	$\leq 20$ nsec for 10 V input
Resolution:	1 part in 1000
Differential Nonlinearity:	$\pm 2.0\%$ from 5 to 100% full scale at 10 nsec gate width
Sensitivity:	0.25 pico coulombs
Conversion Time:	$\leq 50$ $\mu$ sec

Gate Rise and Fall Time:  $\leq 1 \text{ nsec}$   
Gate Width: Variable from 10 nsec to 50 nsec in  
10 nsec increments

### 3.1.3 Control/Gating and Synchronization Unit

A control/gating and synchronization unit is required to provide a synchronous drive to the laser transmitter, accept laser status, provide appropriate oscilloscope synchronization signals for each mode, and also supply various gate and shutter signals. The unit must generate and supply the following signals for each of the modes:

#### A. General

##### Laser Trigger

Output Drive: 10 V into 1 k $\Omega$  impedance

Output Rise Time:  $< 1 \mu\text{sec}$

Shutter Drive: Allow for interface

Status: 8 bit word register, TTL compatible to accept  
laser status word

Oscilloscope Sync: 1 V into 50  $\Omega$  coincident with altitude  
delay or time digitizer stop #1

Oscilloscope Sync Rise Time:  $< 10 \text{ nsec}$

Gate Module Oscillator:  $> 333 \text{ MHz}$

Oscillator Drive: ECL compatible

Mode Control: 8 bit register - CAMAC dataway compatible  
to select system mode via CPU

#### B. Bathymetry

Laser Clock Drive: 400 pps  $\pm 1 \text{ pps}$

Gate Module Drive Width:  $< 3 \text{ nsec}$

#### C. Fluorosensing

Laser Clock Drive: Selectable 100 - 50 - 25 pps  $\pm 1\%$

Gate Module Drive Width: Selectable 10, 20, 30, 40, 50 nsec

#### D. Ground Truth Camera Control

Timing: Provide interface between RTOD clock serial timing  
and camera timing lights

Drive: Provide drive interface to drive camera at  
appropriate time and rate



### 3.2 Signal Processing Subsystem

#### 3.2.1 I/O Controller

The I/O controller must have the capability to properly interface with the acquisition and housekeeping requirements of the system and provide the means to present data to the status and graphics display in a timely manner. It shall also be capable of formatting data and support information for disc and industry compatible magnetic tape storage. To meet all of the requirements listed above, the I/O controller must have the following specifications and characteristics:

##### Central Processing Unit (CPU)

Word Size: 16 bits

Memory Size: 32 k (modularly expandable to 64 k)

Memory Cycle:  $< 1 \mu\text{sec}$

##### Instruction Executive Speed

I/O:  $< 4 \mu\text{sec}$

Memory Reference:  $< 4 \mu\text{sec}$

Register Reference:  $< 4 \mu\text{sec}$

Arithmetic:  $< 2 \mu\text{sec}$

Extended Arithmetic (divide):  $< 20 \mu\text{sec}$

Index:  $< 6 \mu\text{sec}$

Communications:  $< 10 \mu\text{sec}$

Priority Interrupts:  $> 10$

High Speed Channels (DMA): 2

Transfer Rate:  $> 500 \text{ kHz}$

##### Required Peripheral Compatibility

Teletype

Graphics

Disc

Magnetic Tape

D. A. S.

Memory Protection: Required

Power Fail/Recovery: Required

##### Software Requirements

FORTTRAN IV Compiler

Assembler

Disc operating system  
Real time executive  
Microprogrammable  
I/O driver for all CPU peripherals

Required Interfaces

Timing: 42 bits - LSB = 1 msec

CAMAC: EUR 4100 e and/or AEC-TID-25877 compatible

LTN-51 Attitude Reference:

Digital

Latitude/longitude: BCD - 1/sec, 0.1 min resolution

Ground Speed: BCD - 20/sec, 1 knot resolution

Drift Angle: BCD - 10/sec, 0.1° resolution

Synchro

Pitch/Roll: 3 wire synchro 0.04° resolution  
and 0.2° accuracy

Scan Encoder: Binary 2" = 10.5' resolution

3.2.1.1 Disc Unit

A disc unit will be required to provide a convenient means of storing utility libraries, (compiler, assembler, debugger, diagnostics, etc.) application programs, and momentary data storage. To implement application programs efficiently (using Fortran where applicable) the disc and CPU must be supported by versatile and flexible disc operating system software. In order to satisfy the application requirements, the disc unit must have the following major specifications and characteristics:

Storage Capacity:	> 5 m bytes to satisfy current application requirements (should have greater than 10 m bytes to allow for future expansion)
Average Access Time:	30 msec
Data Transfer Rate:	> 500 k bytes/sec

The disc unit must also have exhibited proven performance in an aircraft environment.

### 3.2.1.2 Programs

The following is a list of the major programs or routines, and their characteristics, required to satisfy system control, acquisition, processing, formatting, storing and recording functions:

#### Operating System

Real time executive

File manager

Utility

Diagnostic

Floating point arithmetic

I/O driver routines for all CPU peripherals

#### Application

Initialization:

Select major mode to be run and take appropriate inputs from keyboard.  
Draw grid and label graphics display.  
Ensure all peripherals are in a ready state.

Housekeeping:

While taking data, determine if system has degraded. If it has, can system continue to gather data? Store correlatable information.

RTOD:

At some applicable system rate, get real time of day and store in data buffer (disc output).

Disc Output:

Dump raw data onto disc after every Ith pulse. I to be determined by the most efficient record size of the system.

Tape Output:

At the end of the data run, the raw data will be played back from the disc file and written onto magnetic tape for a permanent record. Some processing and/or editing will also be performed. If the volume of data is prohibitive some form of compression will be needed before outputting to tape.

Status Display:	Obtain a status word (16 bits) from a particular system element and display it with corresponding indicator. Each element status to be displayed at a predetermined rate.
Graphics Display:	Generate real time graphics display plots to give an indication of the quality and content of the data.
Altitude Delay:	Get value of time digitizer after every pulse. Implement a delay algorithm. The result of the algorithm is output to the delay hardware.
CAMAC Interface:	Upon data ready interrupt, get data through interface and store in disc output buffer. Initiate remainder of tasks to be performed.
Laser Control:	Send repetition rate and other laser control commands
Camera Control:	Every Nth pulse, activate camera.

### 3.2.2 Displays

#### 3.2.2.1 Status Display

A status display is required to provide system and subsystem information relative to the current mode, readiness and functional status. To satisfy this requirement, a subsystem status word in binary coded decimal shall be provided and displayed in sequence, freezing each word for a period of 2 seconds. A unique latch fault indicator must be provided for each subsystem status word in order to alert the operator that a system malfunction has occurred.

#### 3.2.2.2 Graphics Display

A graphics display is required to provide a clear presentation of either single or combined events to the operator for his assessment of data content in real time. The graphics display must have the following specifications to fulfill this requirement:

Modes:	Alpha Numeric - full upper case ASC II character set Graphic - vector in response to CPU commands
Display Area:	4.3 aspect ratio $\approx$ 20 cm x 15 cm - 1000 x 750 addressable points
Display Medium:	Direct view storage CRT
Typical Drawing Time:	< 1 sec for 500 points
Erase Time:	$\leq$ 200 msec
Software:	Operating system compatible and supported with high level graphic generation package for generating grids, scale labeling and array plotting

This unit must also have the capability to select, freeze and update status for a particular subsystem. The following subsystems shall be included in the status presentation:

- CPU
- Laser
- Camac
- Inertial Navigator
- Graphics display
- Disc unit
- Magnetic tape recorder
- Housekeeping interface
- RTOD clock

### 3.2.2.3 Monitor Oscilloscope

A monitor oscilloscope will be required for electronic calibration, alignment, signal monitoring and troubleshooting. To meet these requirements this unit must have the following specifications and features:

Input Impedance:	50 $\Omega$
Number of Channels:	2
Deflection Factor:	$\geq$ 2 mV/div to 5 V/div in calibrated steps

Vertical Deflection: DC to 200 MHz, 1.75 nsec rise time  
Time Base: 0.01 nsec/div to 0.5 sec/div  
Sweep Rate: 1 nsec/div maximum

Triggering:

- 1) Normal (sweep when triggered)
- 2) Single sweep
- 3) Delayed sweep

Display Area: 8 cm x 10 cm

3.2.3 Timing

Timing for the AOL system will be provided by an existing aircraft-mounted Astrodata Model 6220 Universal Time Code Translator. The AOL requires both a parallel RTOD output code which provides a LSB resolution of 1 msec and a serial code with a 1 sec time frame to 1 msec resolution. The Model 6220 can meet this requirement since it can furnish a 44 bit BCD parallel code from 100's of days to units or milliseconds, and also has available a serial NASA, 36 bit, one second time code.

3.2.4 Housekeeping

Several analog and discrete or encoded digital signals are required to be monitored and recorded along with the AOL data, in order to provide supporting information relative to the data gathering instrument settings and configuration.

All of the necessary parameters and position settings required for subsequent processing cannot be determined until the system interdependent variables and subsystem controls have been fully accessed during detail design. The following is a list of items which will probably require monitoring:

- Laser power output and go/no-go diagnostics
- Photomultiplier power
- System mode, identification and calibration settings/status
- Scan encoder position
- Real-time-of-day
- Inertial navigator outputs
- Ground truth camera shutter sync

### 3.2.5 Recording

In order to provide a universal medium for AOL data such that processing and reduction can be accomplished at many computing facilities, a magnetic tape recorder will be required which is capable of formatting, recording and playing back industry-compatible, 9 track, 800 BPI magnetic tape. The unit must be compatible with the I/O controller and be supported with an I/O software driver for the operating system. In addition, it should have a fast data transfer capability (up to 36 k bits/sec), be provided with dynamic braking and accept up to 26.6 cm (10.5 in.) reels.

### 3.3 Power Control and Distribution

A power control and distribution unit is required to properly interface the AOL system to the aircraft. This unit will provide aircraft power to system interfaces, include appropriate EMI/RFI filtering, and provide power protection and branch distribution to the various subsystems. Lamps will be required to indicate power availability from aircraft busses and to the various AOL subsystems. Also, a system power "on" timer will be required to indicate total operating time for equipment maintenance purposes.

## 4.0 DESIGN AND CONSTRUCTION

### 4.1 Environment

The AOL system must be designed to withstand an operational environment in an unpressurized aircraft cruising in clear weather at altitudes up to 1524 m (5000 ft). Under these conditions, the equipment must perform in accordance with the specifications previously stated. In addition, the equipment must survive the environment of high humidity and low temperatures occasionally encountered on the ground, and reasonable shocks encountered during aircraft landings and equipment, installation, and removal. The specifications for these conditions are:

#### 4.1.1 Operational Environment

Temperature:	50° - 100°F
Altitude:	0 - 1524 m (5000 ft)
Humidity:	0 - 95% relative humidity

#### 4.1.2 Survivance Environment

Temperature: 0° - 105°F  
Altitude: 3658 m (10,000 ft)  
Humidity: 0 - 95% relative humidity

#### 4.2 Safety (Crash Landing)

The ultimate design load factors which the AOL system shall meet are:

##### Cabin Area

Forward: 9g      Sideways: 2g      Down: 6g      Up: 3g

##### Instrument Bays (beneath floor)

Forward: 2.5g      Sideways: 2g      Down: 6g      Up: 3g

The design floor load limit is 975 kg/m<sup>2</sup> (200 psf).

#### 4.3 Maintainability

Provisions are to be included for maintaining the AOL equipment in a field environment. Optical surfaces shall be overcoated with hard materials such as Mg F12 or SiO to facilitate cleaning. Corrosion resistance materials are to be used throughout, or protective coatings applied. Access ports shall be provided for periodic inspection of critical areas, and modular construction used to facilitate removal of units for maintenance. Where appropriate, electronic chassis will be slide-mounted for ease of maintenance. Protective shields are to be provided for critical components which are handled separately during installation and removal, such as the scanning mirror. Caution signs will be used where special maintenance procedures are involved, and guides should be provided to assist in relocation of components after removal.

Diagnostic and test features and test points will be considered and built into the equipment wherever feasible. Equipment shall be designed and purchased with due consideration given to ease of maintenance. Quick disconnect connectors will be used wherever possible. Direct unit to unit cabling will be utilized throughout the system to keep interconnections to a minimum and ease signal flow tracing.



#### 4.4 Reliability

Components will be designed or procured with a view toward long life in a field environment. Purchased units will be of good commercial quality and flight worthy. Newly fabricated equipment shall be designed for ruggedness and durability. Mil grade components will be utilized, where justified.

#### 4.5 Electrical

AC power lines will be protected with appropriate circuit breakers. All newly fabricated units will be completely enclosed and bonded to ground. EMI filters will be placed in series with all the input power lines to minimize conducted interference. MIL-I-6181D will be utilized as a design guide with regard to the generation of radio interference (RFI) by the AOL and its susceptibility to RFI.

Where applicable, cables will be shielded and in this regard, MIL-E-5400 K shall be utilized as a design guide.

#### 4.6 Marking, Identification and Finish

MIL-STD-130 will be used as a guide for determination of part and assembly marking requirements. An Avco nameplate marked with the component name and part number shall also be located in such a manner as to be visible in the normal configuration whenever practical. All cables shall be individually numbered and each connector will be identified as to its mating unit.

The exterior surfaces of units shall be painted grey with the optical element holders and surrounding areas, black anodized. Components purchased with suitable finishes will be used in their original configuration.

#### 4.7 Workmanship

MIL-E-5400 K will be used as a design guide in the construction of the system. All workmanship will be of good commercial quality.

#### 4.8 Human Factors

The optical system will be constructed to allow access to the optical elements for cleaning and replacement purposes, with minimum disassembly of major subsystems.

The transmitter portion of the system will be designed such that the direct laser beam or any reflecting beam will not be exposed to eyes of personnel in the aircraft.

The assembly of electronic units in the racks will be arranged for maximum utility and operator convenience. The monitor screen will be located at eye level; controls will be located within easy arms length; patch cables will be of appropriate lengths so as not to obstruct other instrumentation; controls will be grouped by function and lights, switches and circuit breakers will be clearly labeled.

## 5.0 LOGISTICS

### 5.1 Documentation

All drawings for the AOL will be prepared in accordance with MIL-D-1000, Category A, Form 3. In addition, flow charts and signal flow diagrams will be prepared, as required.

Acceptance test plan(s) will be prepared and submitted as required by the contract. In addition, Operations and Maintenance Manual material will be prepared to the level specified by contractual requirements.

### 5.2 Spare Parts

A spare parts list will be provided if required by the contract.

### 5.3 Support Equipment

Support equipment specified by the contract will be provided.

## SECTION VI

### PRELIMINARY DESIGN

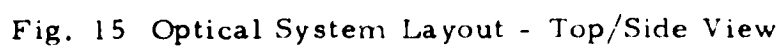
#### 1.0 INTRODUCTION

This section presents data relevant to the preliminary design of the AOL.

#### 2.0 OPTICAL (SENSING) SYSTEM

The AOL optical system is shown installed in the aircraft in Figs. 15 and 16 (dwg 407-218, sheets 1 and 2, respectively). The optical platform is attached to the aircraft floor at Station 600 so that the optical path is centered over the access hatch at that location. The scanner portion of the system is installed under the floor, pointing down through the baggage hatch. Utilization of the baggage hatch is an important feature in the design since the latter is the only present opening in the aircraft which has sufficient size to permit the use of the largest scanning angle required, namely  $\pm 15^\circ$  from vertical. To accommodate the  $15^\circ$  scan angle, the rotating scanning mirror is positioned close to the opening in the skin, and a fixed mirror is used to deflect the return beam from the rotating mirror up through the floor access hatch. The locations of transmitter and receiver components are chosen to provide a compact arrangement with maximum accessibility to the laser elements and with due consideration for access to the removable portions of the receiver as well. In locating these modules, careful consideration was given to the close proximity of the electronics racks already present on NASA aircraft N427NA. The racks are as shown in Figs. 15 and 16 and, in this location, adequate clearance for AOL components is provided.

The optical platform is attached to the floor through isolators, and the scanner assembly is attached to the optical platform by rigid stand-offs which pass through the aircraft floor. The units, optical platform and scanner, are therefore rigidly coupled together but are separable for installation and removal. The estimated weights are 281 kg (620 lbs)



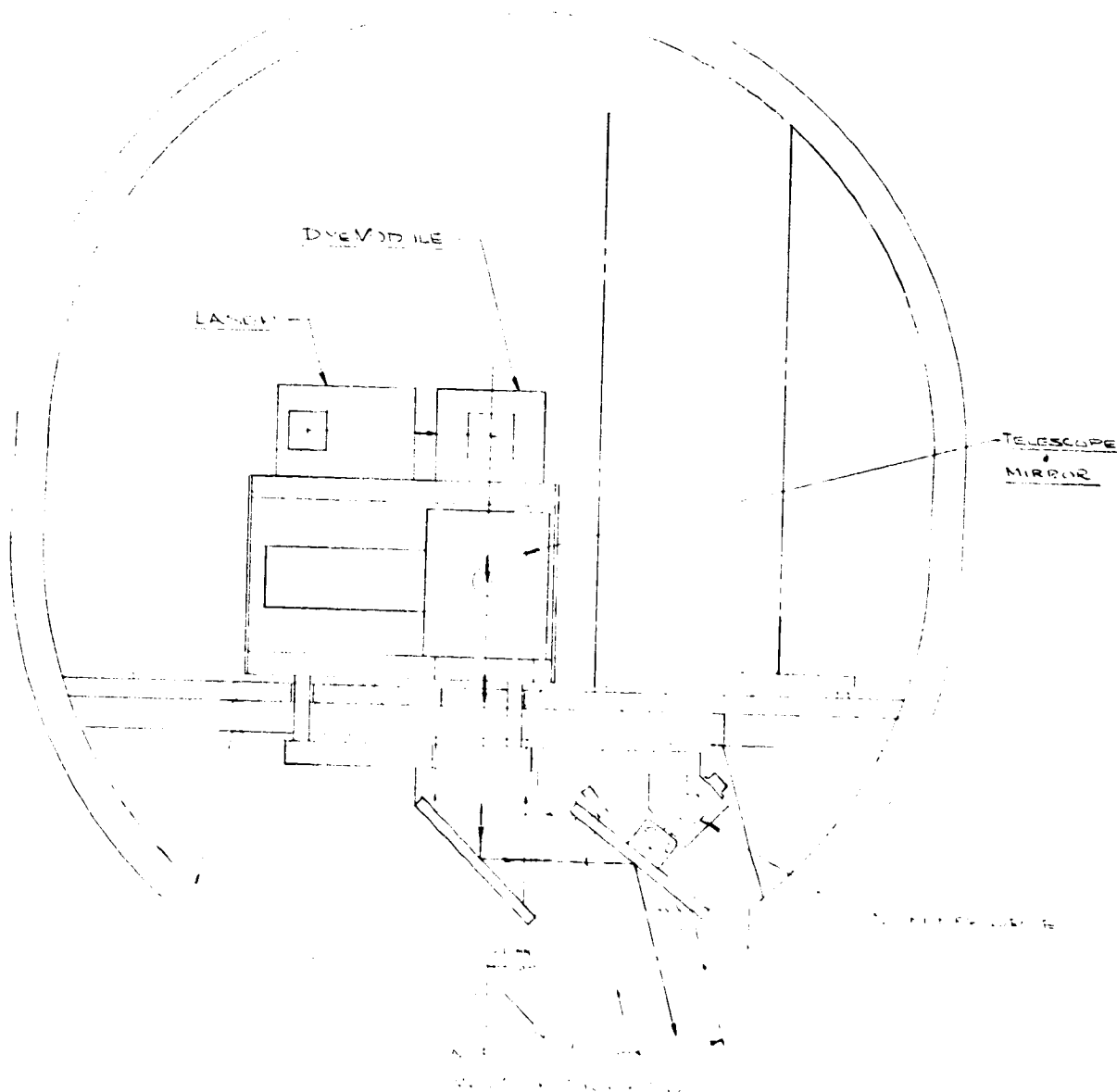
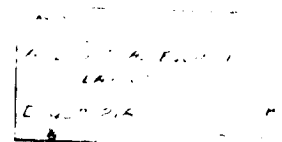


Fig. 16 Optical System Layout - End View



for the optical platform assembly (which includes all transmitter and receiver elements), and 90 kg (200 lb) for the scanning assembly. These weight estimates are further detailed in a subsequent section of this report.

## 2.1 Optical Considerations/Design

An overall view of the various optical components is shown on Fig. 17 (dwg 407-223). On this drawing, the effective element apertures and spacings are shown to scale. In certain cases, however, the optical path is shown 90° out of position for graphical purposes. For a true depiction of the optical path, the reader is referred to Figs. 15 and 16.

Before an examination of the equipment design is undertaken, it is important to understand the fundamental image relationships in the optical system. This section will therefore be devoted to an explanation of the relationships that affect focal length and f-number selections, spectral resolution, and depth-of-field.

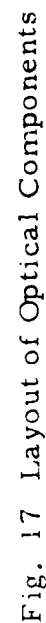
### 2.1.1 Selection of Focal Lengths and f-Numbers

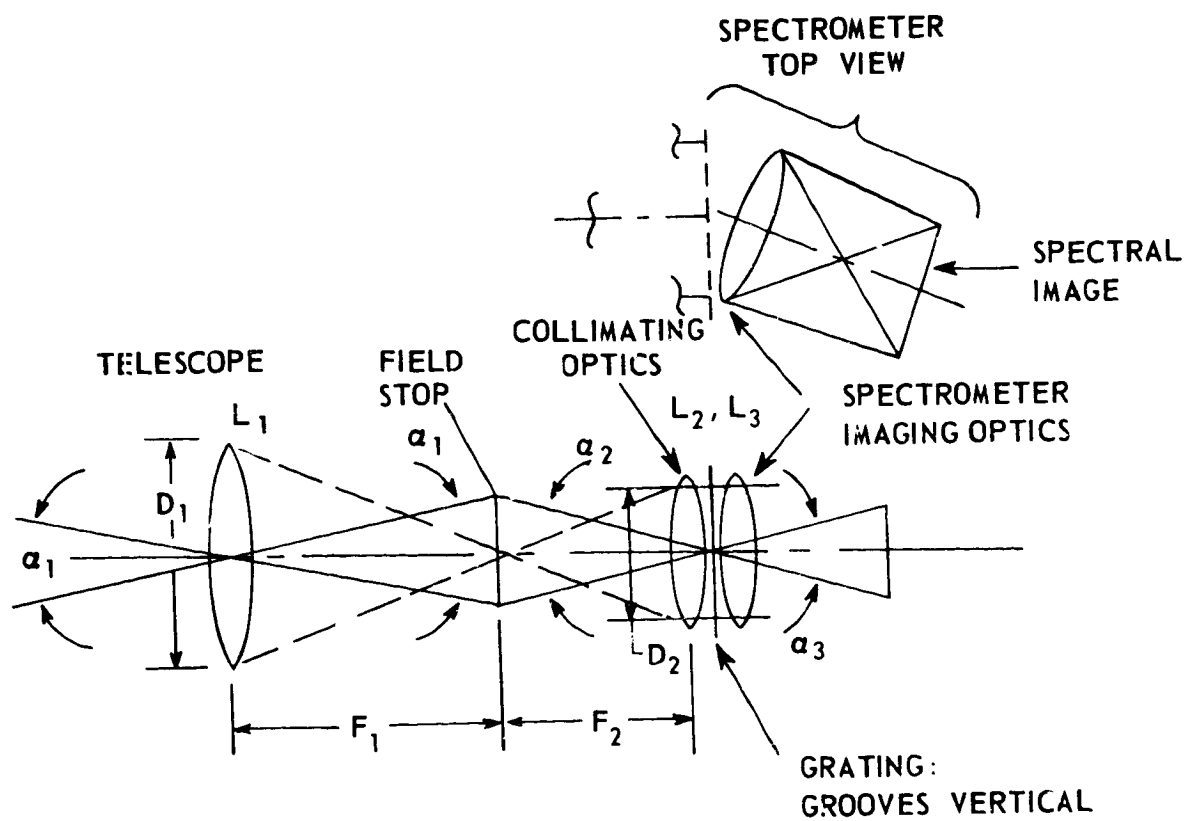
The size of the collecting optics is fixed at the largest practical diameter to match the available openings in the aircraft floor.

The choice of system f-number is dictated primarily by consideration in the spectrometer. For a large number of reasons, including cost and mechanical integrity, it is highly desirable to use single element lenses. When single element lenses are faster than  $f/4$ , an inordinate amount of image aberration is introduced. When they are slower than  $f/4$ , the required optical paths become too long for the allowable space in the aircraft. Thus  $f/4$  provides a reasonable compromise.

An additional consideration supporting the  $f/4$  choice is provided by the telescope. The telescope must be the same  $f/\#$  as the recollimating lens and must also be reflective and telephoto, i. e., have a focal length longer than its physical length. Thus it must be of a form similar to the cassegrainian. The component mirrors of a cassegrainian telescope are necessarily faster than the telescope assembly, becoming very difficult to manufacture and align for telescopes much faster than  $f/4$ . Therefore, a cassegrainian telescope much faster than  $f/4$  is not very practical.

In describing the image relationships of the receiver, the optical components can be depicted schematically, as shown in Fig. 18. In this figure, the following definitions and relationships apply:





E9489

Fig. 18 Receiver Image Relationships



Telescope Dia =  $D_1$ ; Focal Length =  $F_1 = 1220$  mm

Telescope FOV =  $\alpha_1$  to match the transmitter divergence

Telescope,  $L_1$  and Collimating Optics,  $L_2$  have matching f-numbers:

$$\frac{F_1}{D_1} = \frac{F_2}{D_2}$$

Angular image sizes are inversely proportional to the focal lengths of the telescope and collimating optics:

$$\frac{\alpha_2}{\alpha_1} = \frac{F_1}{F_2}$$

The angular size of final image is:

$$\alpha_3 = \alpha_2 = \alpha_1 \frac{F_1}{F_2}$$

In this figure, the telescope is collecting light over a field-of-view determined by the field stop, which has been adjusted to match the transmitter divergence. The collimating optics are sized for no vignetting over the field-of-view. The angular magnification of the final image, at any single wavelength, is a function of the target angular subtense and the ratio of lens focal lengths. From the geometry shown in the figure, it is apparent that the smaller the collimating lens focal length,  $F_2$ , the larger the angular magnification  $\frac{\alpha_2}{\alpha_1}$ . This has a significant impact on the spectrometer design.

#### 2.1.2 Spectral Resolution

The spectral resolution of the receiver is affected by the angular dispersion of the grating, and by the angular size of the final image previously discussed. The spectral resolution is approximated by dividing the angular size of the final image by the angular dispersion, which is a first order approximation which does not take into account the effect of defocusing, or the size of the detector element.

Two gratings were considered during the preliminary design phase and the spectrometer characteristics with these gratings are shown in Table X. The effect of increasing the collimating lens focal length is also shown.

TABLE X

## SPECTROMETER RESOLUTION

Grating Frequency (g/mm)	Angular Displacement (mr/Å)	Collimating Lens Focal Length, F <sub>2</sub> (mm)	Angular Resolution $\alpha_1 \times F_1/F_2$ where $\alpha_1 = 2$ mr (mr)	Angular Resolution $\alpha_1 = F_1/F_2$ where $\alpha_1 = 3$ mr (mr)	Spectral Resolution for $\alpha_1 = 2$ mr (Å)	Spectral Resolution for $\alpha_1 = 3$ mr (Å)
900	.09	400	6.1	9.15	67.7	101.6
600	.06	600	4.06	6.1	67.6	101.6
600	.06	400	6.1	9.15	101.6	152.5

Initially an attempt was made to develop a spectrometer layout with a 900 g/mm reflection grating covering the broad bandpass of 3500 - 8000 Å. When this attempt was not successful due to the space constraints imposed on the AOL optical configuration, the present layout was developed utilizing a transmission grating. Of the transmission gratings currently available, the 600 g/mm gratings have considerably higher efficiency, particularly in the near ultra-violet. Two designs were then considered using collimating lenses of 400 mm and 600 mm focal length. The table shows the two possible spectrometer designs based on the 600 g/mm grating. The 600 mm focal length design achieves better spectral resolution, but the focal lengths and diameters of both the collimator and the spectral imaging lenses would be too large to fit within the desired space. Using a transmitter beam divergence operational range of 2-3 mr for fluorosensing, the practical choice of a grating produces a spectral resolution of 100 - 150 Å for best broad band transmission and for reasonably compact packaging. This is quite compatible with the resolution requirements imposed on the system in the fluorosensing application.

### 2.1.3 Telescope Depth of Field

A basic question in the telescope design is whether the system can operate over the required range of altitudes without being subjected to a mechanical refocus. The origin of the problem is best understood if visualized in reverse, i. e., the telescope forms an image of the field stop on the ground. The image is formed for some nominal altitude, and for other values of altitude, this field stop image will be somewhat blurred because of defocus. If the nominal field stop image is equal to or larger than the illuminated patch of ground, this blurring will decrease the signal-to-noise (background) ratio. Since this defocusing will affect system performance most severely in the fluorosensing mode of operation, the telescope will be focused for a 152 m (500 ft) aircraft altitude. This means that there will be no blurring from defocus during fluorosensing, when a narrow receiver field-of-view is used (2-3 mr). During bathymetry measurements, where aircraft altitude will vary between 152 m and 609 m, the maximum blur from defocusing will be 1.5 mr. This blurring is insignificant when compared to the wider receiver fields-of-view used in bathymetry measurements (13-20 mr).

In summary, depth of field should pose no serious problems for the proposed configuration over the desired operating ranges. <sup>(1)</sup>

## 2.2 Equipment Design

In this section, the various functional module designs will be described separately.

### 2.2.1 Transmitter

In Fig. 15, the nitrogen laser and dye module are shown with two laser folding flats directing the beam from one unit to the other. The nitrogen laser can be used without the dye module, or other lasers can be used as needed by arranging the folding flats to direct the laser beam into the transmitting optics.

In the transmitting optics housing are included the laser filter, polarizer, and beam expander. The sizes and arrangement of these elements are shown in Fig. 17. The laser filter and polarizer are both detachable since their use is dependent on the choice of laser and application.

The beam expander provides control of beam divergence by means of a manual adjustment on one of the two lenses. Using lenses of the focal length and spacing shown in Fig. 17, the range of adjustment is approximately 17 mm for a divergence of 20 mr. The two lenses are fused silica, AR coated for best transmission in the region between 3300 and 6600 Å.

The transmitter folding flat is a diagonal mirror of adequate size to accommodate the 100 mm output beam of the transmitter. It is aluminized and overcoated for reflectivity favoring the spectral region between 3300 and 6600 Å, and it is provided with pointing adjustments for aligning the output beam to the receiver axis.

Two safety shields are provided to obscure the laser beam from view. One covers the path from the laser to the dye module, the other covers the beam path from the transmitter folding flat to the hole in the receiver folding flat.

---

<sup>(1)</sup> Factory refocusing for different ranges will be possible since this adjustment will be incorporated in the design of the receiver telescope.

### 2.2.2 Receiver Folding Flat

In Fig. 19 (dwg 407-226) is depicted the mount for supporting the receiver folding flat at  $45^\circ$  to the path of the return beam. The flat is of lightweight aluminum construction and is supported kinematically with pointing adjustments at the three mounting points to provide a means of aligning the receiver pointing axis to a datum. The mirror is also removable for direct access to the telescope collecting aperture. The center of the mirror is bored to an aperture large enough to pass the transmitter beam without vignetting.

### 2.2.3 Telescope

Figure 20 (dwg 407-225) shows a cross-sectional view of the cassegrainian telescope. The optical components are comprised of a primary mirror mounted directly to the housing, and a secondary mirror mounted in a spider which is adjustable for initial focusing of the telescope. Baffles are provided with a provision for adjusting the primary baffles to the most effective position for the selected field stop setting. The sizes and focal lengths of the mirrors are as specified in Fig. 17.

### 2.2.4 Collimating Optics and Field Stop

Fig. 21 (dwg 407-229) shows the optical path leading from the adjustable field stop up to the collimating lens. The field stop is located at the focal plane of the telescope and consists of two pair of knife edges at  $90^\circ$  which are remotely activated from a control panel. Each pair of knife edges is centered on the optical axis and is provided with an independent drive motor. The horizontal and vertical separations of the knife edges can be adjusted to provide field-of-view settings from zero to 20 mr.

A diagonal mirror is provided to fold the optical path, and a check lamp is located behind the mirror. A center hole in the mirror provides an optical path from the lamp to the spectrometer and bathymetry detectors. This feature provides the capability of performing checks on the operation of each detector assembly by simply switching on the check lamp. The center hole in the mirror is made small enough to fit within the central obscuration of the receiver beam so that it causes no loss of return signal.

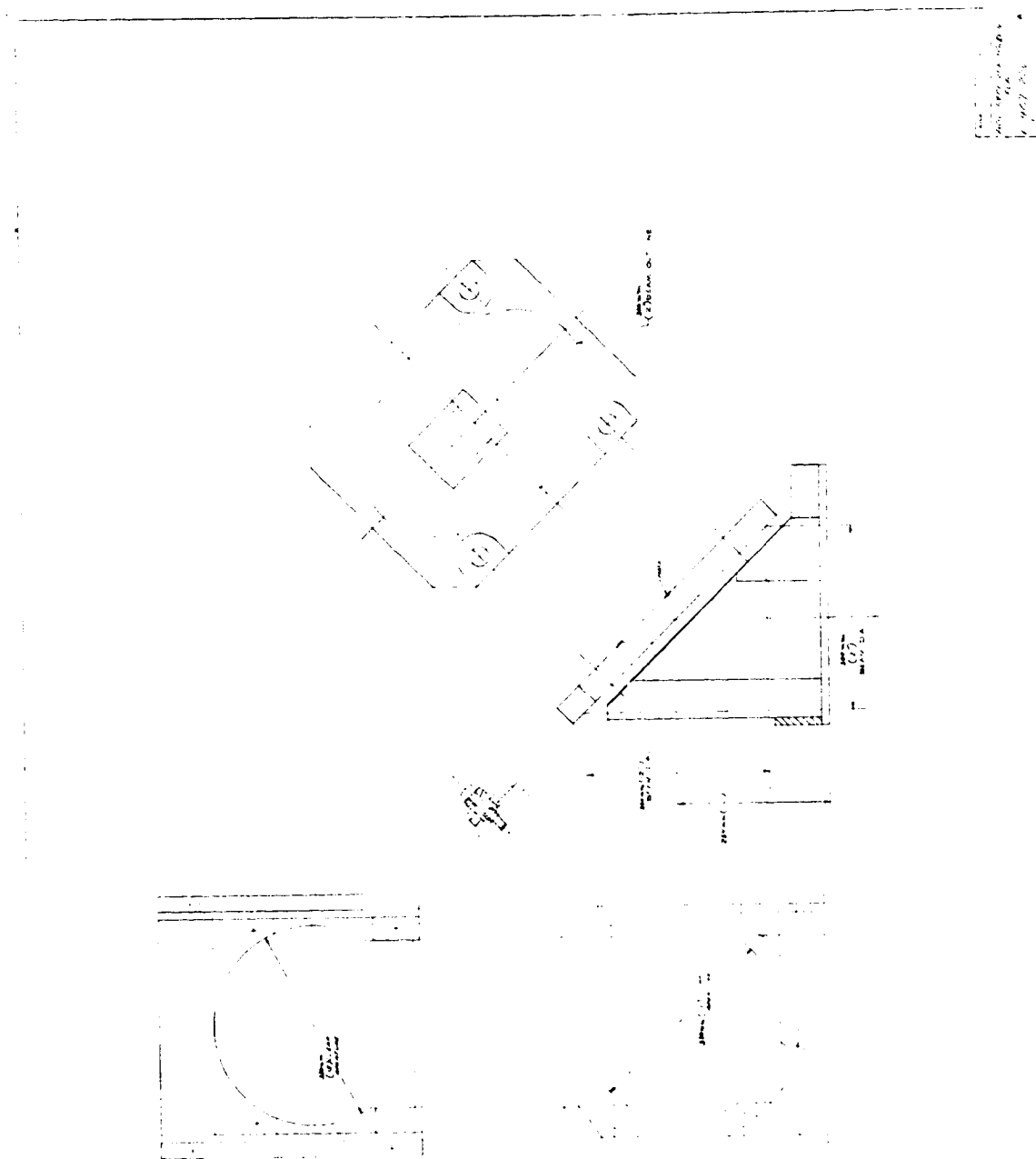
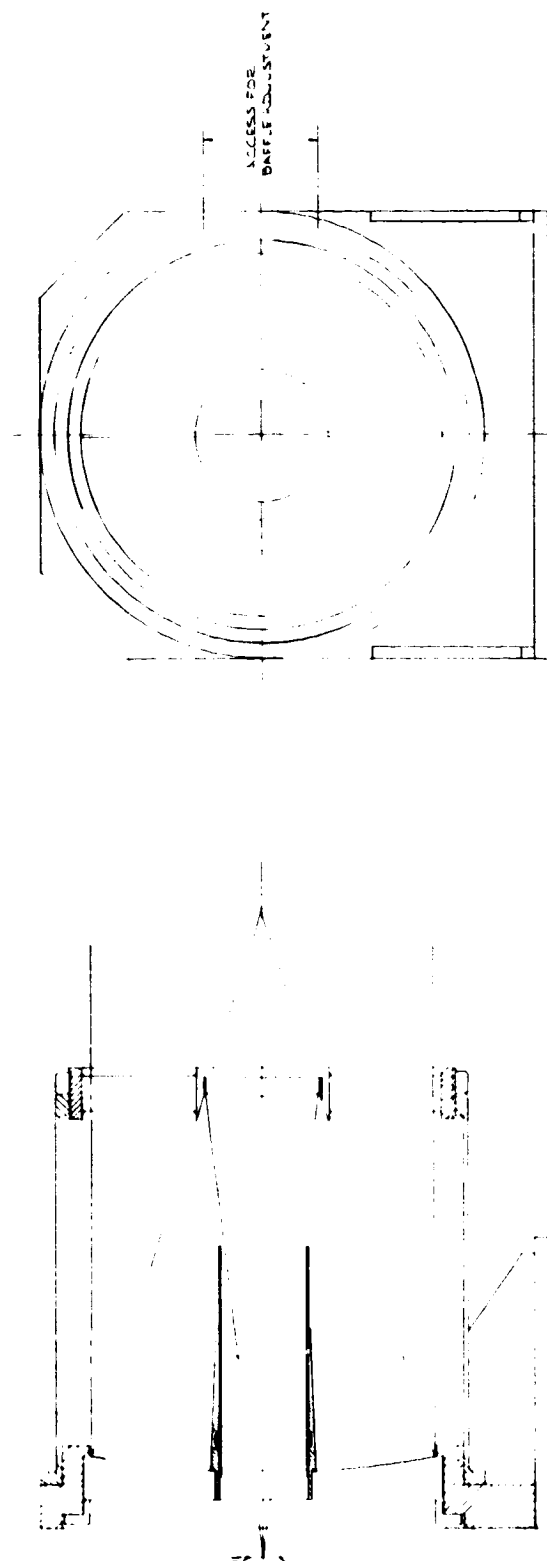


Fig. 19 Receiver Folding Flat



JAMES E. BENTLEY RESEARCH LABORATORY, INC.	
1001 CASSEGRAINIAN	
TELESCOPE	
NO.	407-225
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Fig. 20 Cassegrainian Telescope Assembly

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
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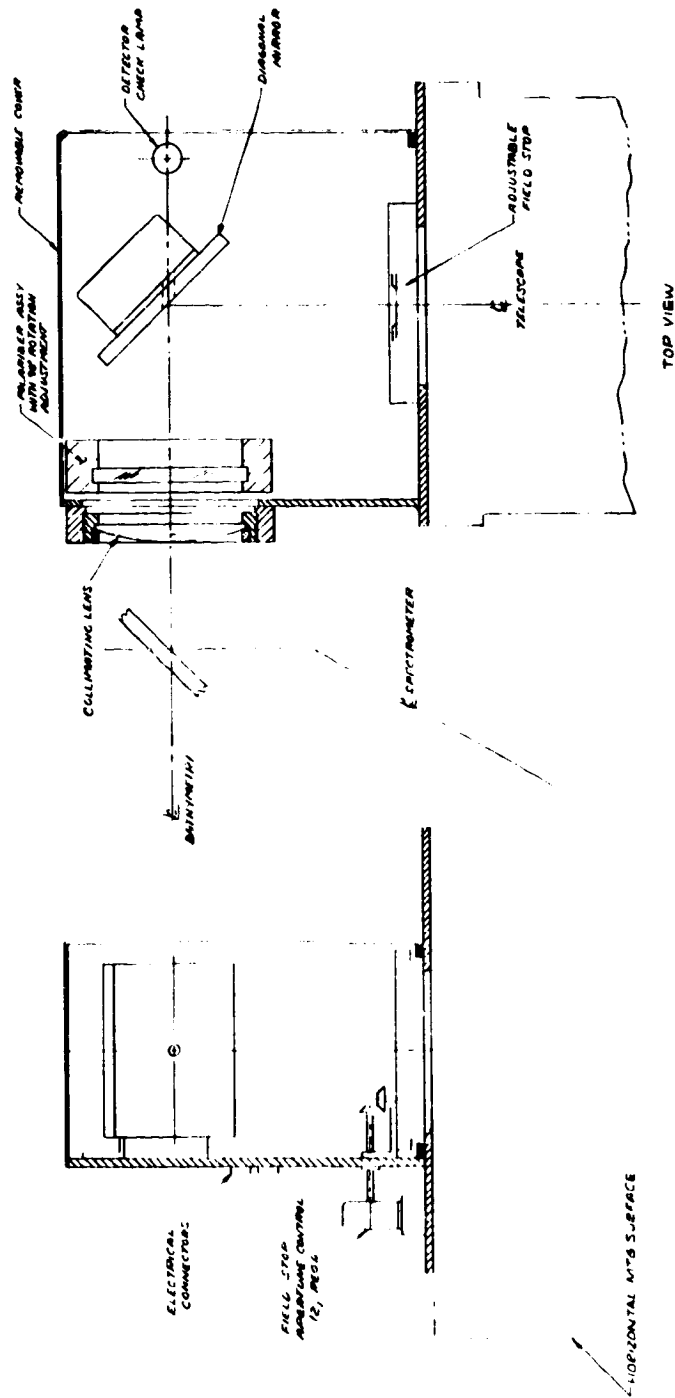


Fig. 21 Collimating Optics

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
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A linear polarizer is provided in the optical path just prior to the collimating lens, with provisions for removing the polarizer if necessary, or for adjusting the polarizer to a specific angle.

The entire collimating optics and field stop assembly is fastened directly to the back plate of the telescope to maintain rigid alignment with the telescope axis. A cover plate is provided for access to the lamp and polarizer.

#### 2.2.5 Bathymetry Optics

Figure 22 (dwg 407-228) shows the housing which contains the removable flip mirror that directs the incoming beam over to the spectrometer. The mirror is slide mounted so that it can be removed for bathymetry; in which case the incoming beam passes to a spectral filter, a converging lens, and a neutral density filter. The filters are slide mounted for manual removal, and a light tight panel is provided for access to the filter slides. The access panel is located on the forward wall close to the edge of the platform for ease of access.

The bathymetry optics assembly is attached to the horizontal surface of the optical platform and is aligned with the collimating optics assembly by direct contact between the units. The interface between the two optical units occurs in a collimated portion of the beam so that translational shifts will not affect the image locations.

#### 2.2.6 Spectrometer and Detector Array

Figure 23 (dwg 407-227) shows the spectrometer components including the grating, imaging lens, light guides, and multi-channel detector array. The optical axis of the unit is positioned at  $20.4^\circ$  with respect to the incoming collimated beam in order to center the 3500 to 8000 Å region of the dispersed image onto the light guide array.

The spectral image is divided into 40 channels by arranging light guides side-by-side over the 3500 - 8000 Å bandwidth. Using an f/4 imaging lens of 100 mm diameter, the focal length is 400 mm, and the length (L) of the spectral image is:

$$L = .06 \text{ mrad/Å} \times 10^{-3} \times (8000 - 3500 \text{ Å}) \times 400 \text{ mm} = 108 \text{ mm}$$

The width of each light guide (W) is:



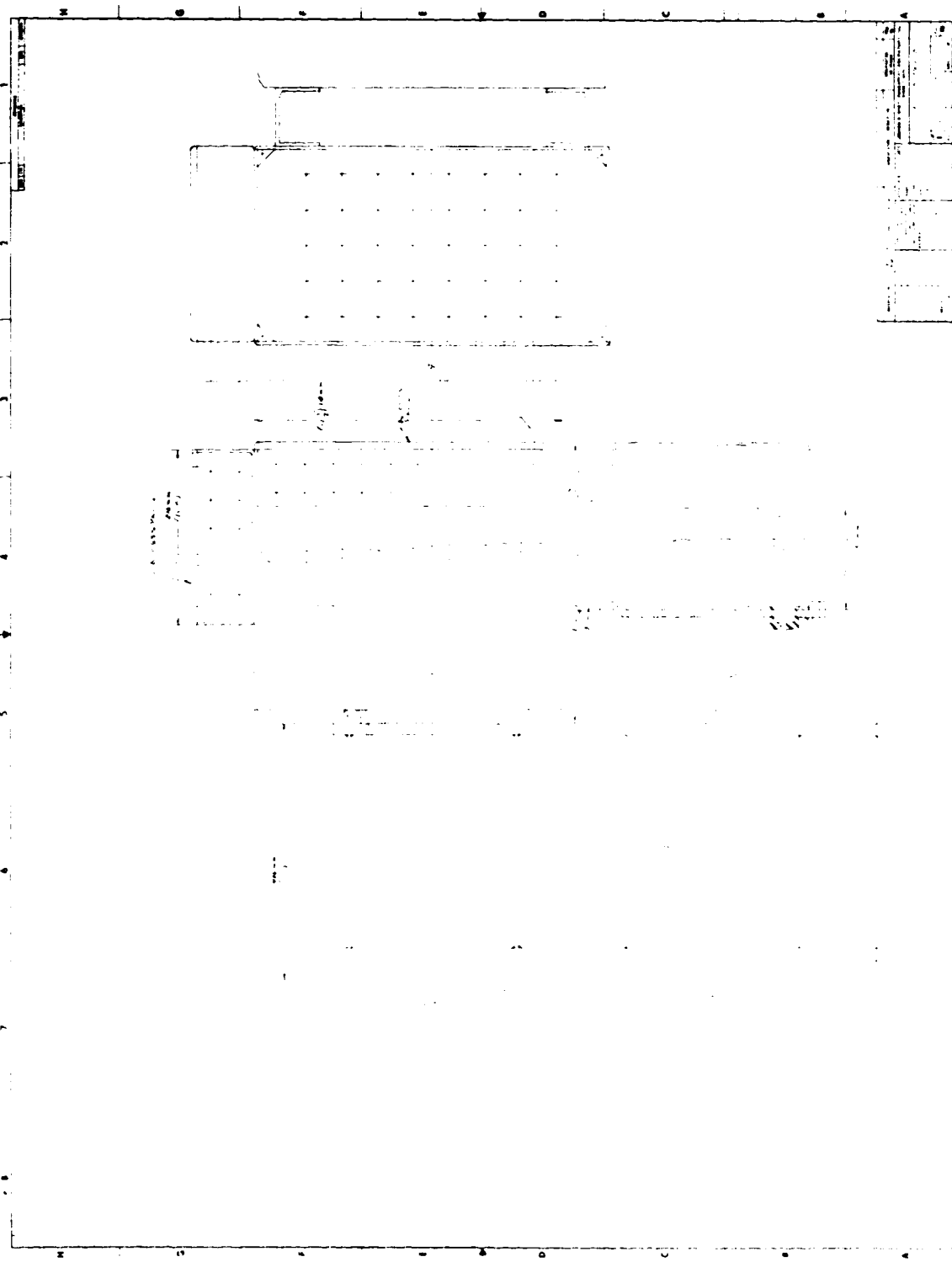


Fig. 23 Spectrometer Assembly

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$$W = \frac{108 \text{ mm}}{40} = 2.7 \text{ mm}$$

The height of each light guide is chosen to accommodate a 5 mr field stop setting with 0.5 mr allowance at both edges. The height (H) is:

$$H = a_3 F_3 = a_1 \frac{F_1}{F_2} \times F_3$$

$$H = .006 \text{ rad} \times \frac{1200}{400} \times 400 = 7.2 \text{ mm}$$

The light guides are bonded together at the entrance end and are curved to fan out to the 40 detectors. A special fitting is provided to hold each light guide in close contact with the face of each PM tube. A suitable grease is provided at the interface to reduce the transmission loss.

The light guides will consist of either fibre optics or clad rods of the proper proportions, depending on the availability of materials with suitable transmission in the spectral regions desired.

Each tube is contained in a shielded housing with its associated circuitry and wired to a bank of connectors located along the top and far side of the detector housing. Removable panels are provided for access to the wiring connections.

#### 2.2.7 Optical Platform and Mounting Details

Figure 24 (dwg 407-224) shows the two-tiered platform for supporting the transmitter and receiver components in their respective locations. The upper shelf has a sufficiently large opening to accommodate a 100 mm transmitter beam while the lower shelf has a large opening for the 305 mm dia return beam. The rectangular access hatch is also shown in the floor of the aircraft beyond the area covered by the return beam, through which two standoffs are located for supporting one end of the scanning assembly. The other end is supported by two standoffs which pass through clearance holes in the aircraft floor. These two clearance holes of approximately 7.6 cm (3 in.) in diameter will be a required modification for installing the system in the aircraft.

The lightweight construction of the platform panels is represented in cross section. The panels achieve their stiffness by means of two sheets of aluminum spaced far enough apart to produce the desired section

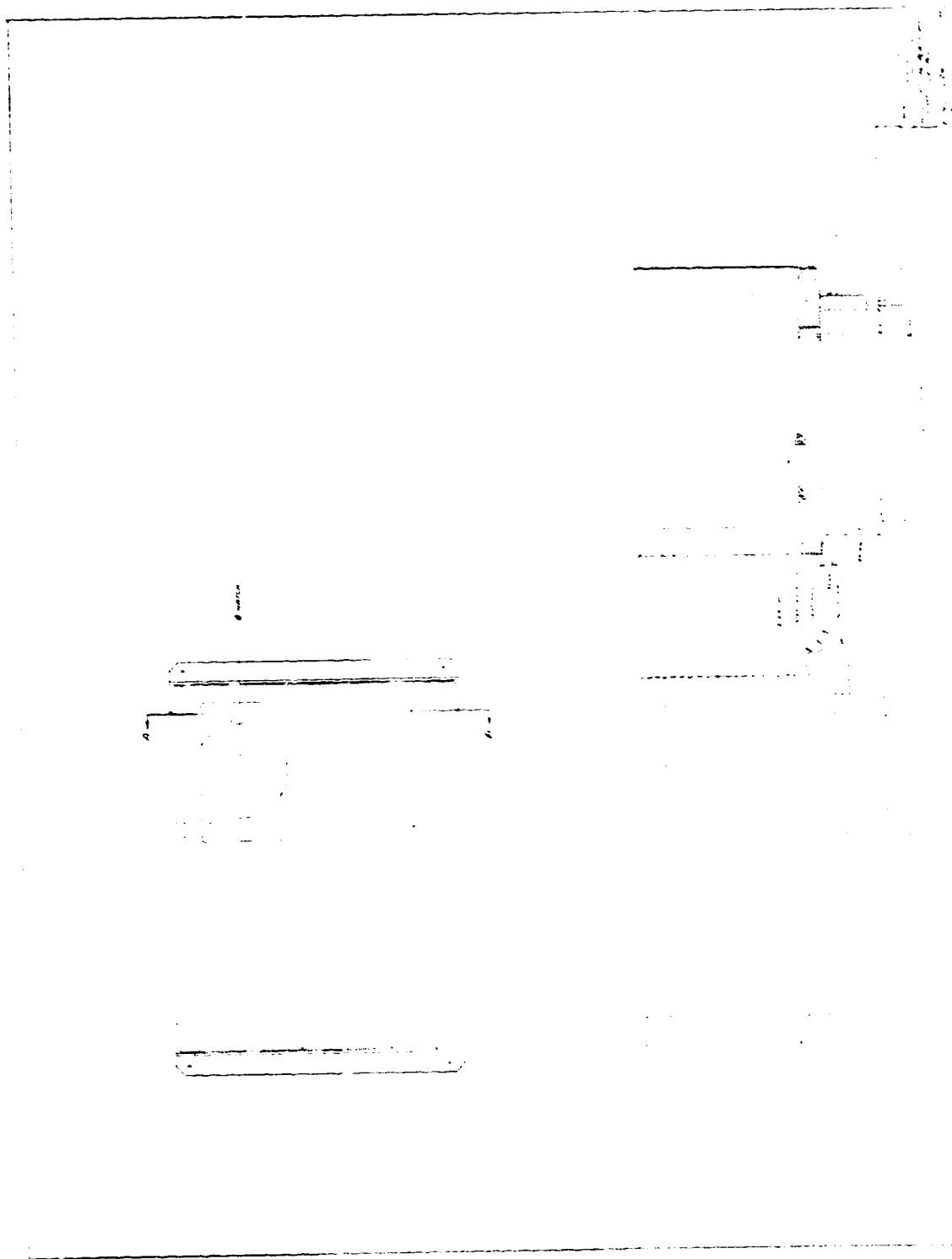


Fig. 24 Optical Platform and Mounting Detail

modulus. The sheets are fastened to channels which serve to maintain the registration of the sheets and thus resist flexure. The sheets are fastened to the channels by many removable fasteners so that a large selection of fastening points is available for attaching components. Additional spacers are also provided at high-load points such as the standoff locations.

The combined load of the optical platform and scanner assembly is supported on isolators located outside the platform area as shown, or directly underneath, if preferred. The interface between the isolators and the aircraft will be designed by NASA and is expected to utilize the existing seat rails shown under the isolator.

#### 2.2.8 Scanner Assembly

The size of the scanner mirrors is shown on Fig. 17 and their orientation is shown on the equipment layouts, Figs. 15 and 16. Since the scanning pattern is oval-shaped, the mirrors are arranged so that the long dimension of the scan pattern is perpendicular to the aircraft fore-aft axis. The rotating mirror is attached to the drive shaft by a hinged joint so that the mirror can be set perpendicular to the drive shaft and at various small angles up to  $7.5^\circ$  so that the scan angle will vary up to  $15^\circ$  from the vertical reference axis. The angle must be adjusted manually prior to a flight.

The mirror drive shaft is supported in ball bearings and a shaft is driven by an electric motor through bevel gears at a fixed rate of 5 rev/sec.

The scanner assembly is installed by lifting the unit through the baggage hatch up to the underside of the aircraft floor. The scanner platform is then fastened to the underside of the optical platform by means of long bolts and standoffs which pass through the floor of the aircraft.

#### 2.2.9 Optical System Weight Estimates

All of the equipment modules in the optical portion of the system are shown below with a weight allocation assigned to each. These weight allocations represent the lowest estimated values achievable using conventional methods of lightweight construction.

<u>Equipment Item/Module</u>	<u>Est. Weight (kg)</u>
Nitrogen laser	68
Dye module	18
Laser optics	12
Receiver folding flat	20
Telescope	27
Collimating optics and bathymetry detector assy	14
Spectrometer and detector assy	27
Optical platform	<u>95</u>
Subtotal	281 (620 lbs)
Scanner mirrors (2)	40
Scanner platform and motor drive	<u>50</u>
Subtotal	90 (200 lbs)

### 3.0 ELECTRONIC SYSTEM

#### 3.1 Control and Data Acquisition

As has been discussed in Section III of this report, the key module which provides a large degree of commonality for satisfying both the bathymetry and fluorosensing data acquisition requirements is the Ortec QD 410 charge digitizer. Referring to Fig. 2, once the signal is detected and amplified appropriately in each mode, it is presented to the input of the QD 410 to be captured and subsequently processed. The only difference from then on is in the capture mechanism or method of gating. In the bathymetry mode, since the measurement is primarily directed towards temporal information, forty charge digitizers will be sequential gated to provide a time history of the energy detected by the bathymetry photomultiplier. In the fluorosensing application, the major interest is in the laser induced fluorescence as a function of wavelength. In this mode, the forty charge digitizers (channels) will be gated simultaneously to detect the incident energy at each wavelength. At this point, the information obtained is transferred to the I/O controller and processed according to the requirements of the chosen mode. Now that the basic details have been explained, the signal flow and module characteristics associated with each

mode of operation can be discussed. Prior to this, however, the rationale for the selection of photomultiplier detectors for each application will be presented.

### 3.1.1 Photomultiplier Selection Considerations

#### A. Bathymetry

Several photomultiplier tubes were evaluated against the requirements for the bathymetry application and those which came closest to meeting these requirements are delineated in Table XI, along with their major characteristics. Figure 25 is a plot of quantum efficiency vs wavelength of the tubes considered. The C31024 was found to have the most favorable performance characteristics and physical package dimensions for the application. It has the best rise time and comparable performance characteristics for those parameters important to the application. The C31034A has a very high quantum efficiency at 540 nm but was not chosen due to the difficulty in integrating a tube with such a small aperture plate (0.76 x 2.28 cm) into the optical train.

#### B. Fluorosensing

The photomultiplier tubes which appear to satisfy the fluorosensing requirements are shown in Table XII. Two of the tubes, the R647 and R761, are packaged in a 1.27 cm (0.5 in.) diameter envelope which would be convenient for packaging and interfacing to the spectrometer light pipes. The quantum efficiency (QE) of these tubes however is lower than that obtainable from the 1.9 cm (0.75 in.) tubes indicated in the Table and this dictates the choice of the larger tubes for use in this application.

Figure 26 is a plot of wavelength vs quantum efficiency for those tubes considered for use. From the figure, it can be seen that the 8644 is the best choice for the first seventeen spectral channels and that the C70042K is optimum for the remaining twenty-three.

### 3.1.2 Bathymetry Data Acquisition

The basic block diagram in Fig. 27 shows the data acquisition signal path which will be used in the bathymetry mode. In order to satisfy the system measurement requirements, all elements within the signal path must have very fast response times and propagation delays that are minimal and predictable. Figure 28 indicates the components and modules



TABLE XI  
CANDIDATE BATHYMETRY PM TUBES

Characteristic	PHOTOMULTIPLIER MODEL NUMBER			
	C31024	8575	C31000A	C31034A
Q.E. @ 540 nm	7.6%	8.5%	11.5%	32.5%
Q.E. @ 400 nm	26.8%	24.5%	23.8%	42%
Risetime	$1.2 \times 10^{-9}$ sec @ 3000 V	$2.1 \times 10^{-9}$ sec @ 3000 V	$2.1 \times 10^{-9}$ sec @ 3000 V	-
		$2.8 \times 10^{-9}$ sec 2000 V	$2.8 \times 10^{-9}$ sec 2000 V	-
Gain	$1 \times 10^7$ @ 3500 V	$1.4 \times 10^7$ @ 2000 V	$3.5 \times 10^6$ @ 2000 V	$4 \times 10^6$ @ 2000 V
	$5 \times 10^6$ @ 3000 V	$7 \times 10^5$ @ 1500 V	$2 \times 10^5$ @ 1500 V	$3 \times 10^5$ @ 1500 V
Dark Noise	$1 \times 10^{-8}$ amp	$1 \times 10^{-9}$ amp	$5 \times 10^{-9}$ amp	$5 \times 10^{-8}$ amp
Max. Anode Current	$0.1 \times 10^{-3}$ amp avg.	$0.2 \times 10^{-3}$ amp avg.	$1 \times 10^{-3}$ amp avg.	$100 \times 10^{-9}$ amp avg.
Max. Supply Volt.	3500 V	3000 V	3000 V	2200 V
Special Notes	--	--	--	0.76 x 2.28 cm aper- ture plate

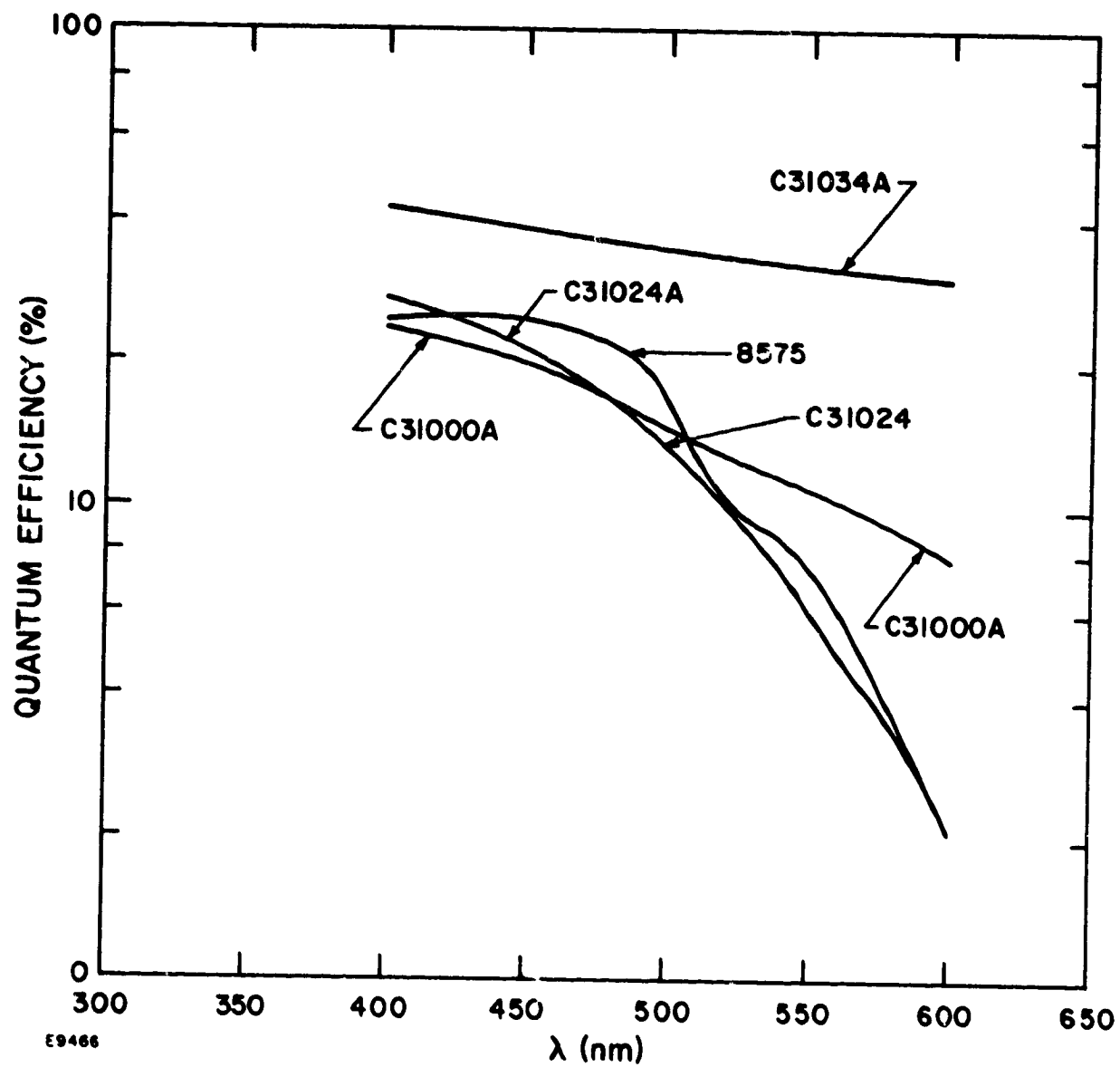


Fig. 25 Bathymetry PMT Quantum Efficiency vs Wavelength

TABLE XII  
CANDIDATE FLUORESCENSING PM TUBES

Characteristic	PHOTOMULTIPLIER MODEL NUMBER			
	R647	R761	8644	C70042K
Q. E. @ 800 nm	--	0.34%	--	3.4%
Q. E. @ 700 nm	--	1.7%	--	5.4%
Q. E. @ 600 nm	2.0%	5.5%	--	9.1%
Q. E. @ 540 nm	--	--	10%	10%
Q. E. @ 500 nm	10%	11.0%	12.7%	--
Q. E. @ 400 nm	14%	15%	19%	--
Gain	$6 \times 10^6$ @ 1200 V	$5.8 \times 10^5$ @ 1500 V	$7 \times 10^5$ @ 2000 V	$7 \times 10^5$ @ 2000 V
	$1.6 \times 10^6$ @ 1000 V	--	$8 \times 10^4$ @ 1500 V	$8 \times 10^4$ @ 1500 V
Dark Noise	$5 \times 10^{-9}$ amp	$1 \times 10^{-8}$ amp	$3 \times 10^{-9}$ amp	$6 \times 10^{-9}$ amp
Max. Anode Current	0.01 ma avg.	0.01 ma avg.	0.1 ma avg.	0.5 ma avg.
Max. Voltage	1250 V	1800 V	2100 V	2100 V
Diameter	1.27 cm	1.27 cm	1.9 cm	1.9 cm

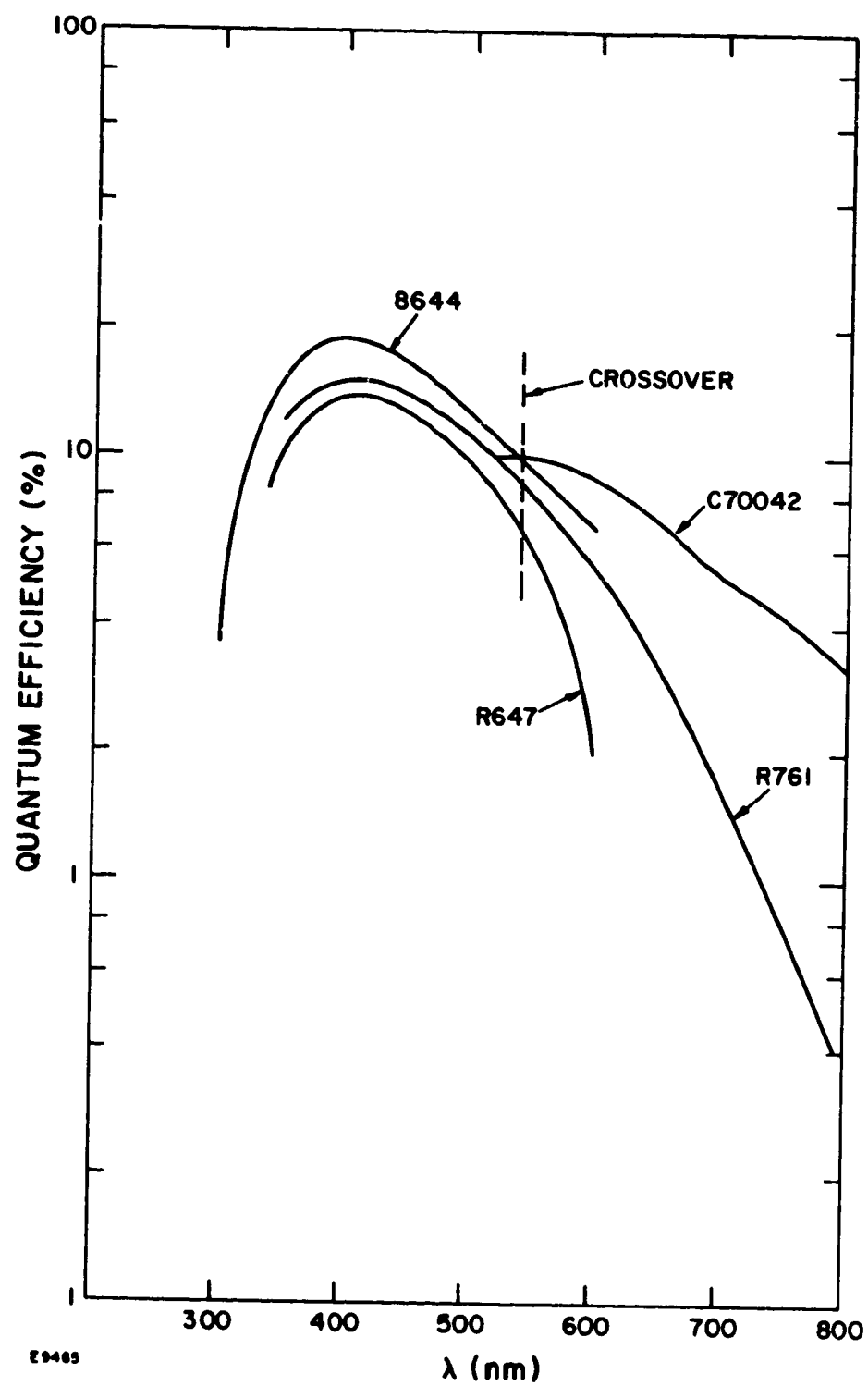


Fig. 26 Fluorosensing PMT Quantum Efficiency vs Wavelength

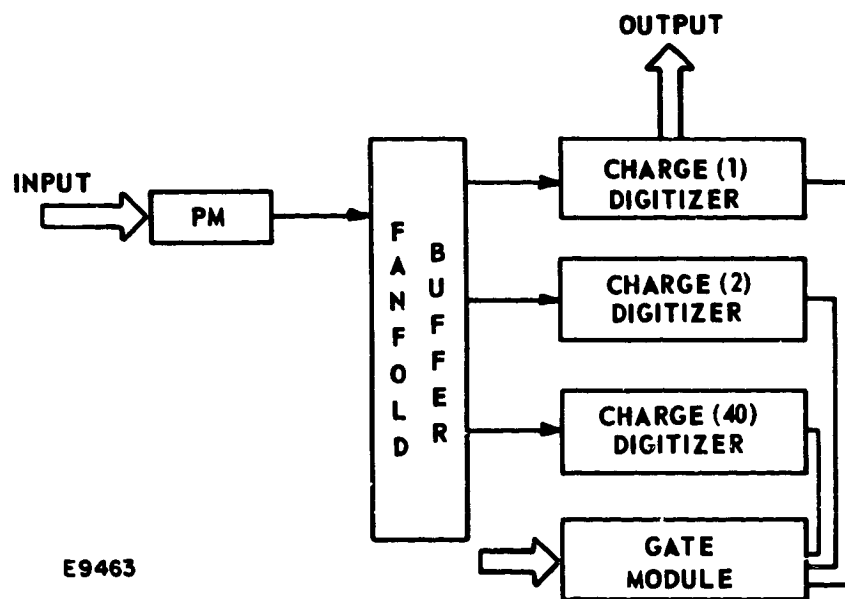


Fig. 27 Data Acquisition Block Diagram - Bathymetry

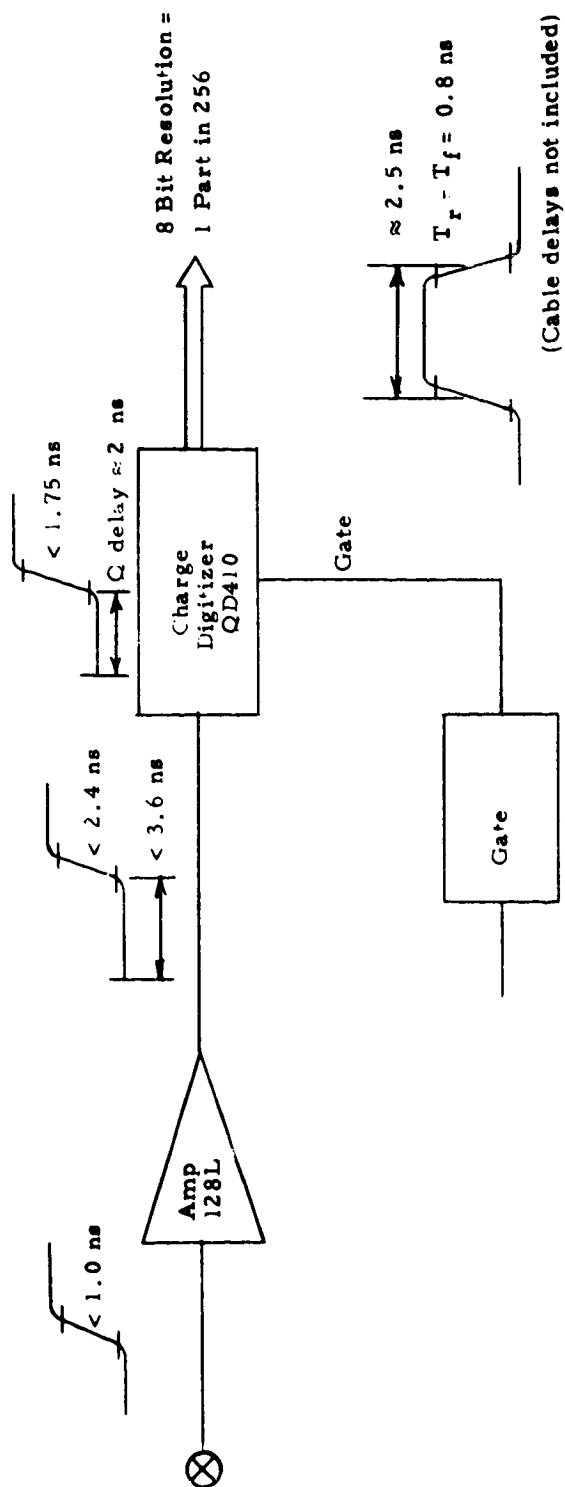


Fig. 28 Bathymetry Signal Path Tolerances

chosen to satisfy this requirement along with their associated rise times and tolerances. The input starts with the C31024 photomultiplier which has a signal rise time of less than one nanosecond for a single electron event. The signal then passes through the model 128L Amplifier to the QD410 charge digitizer. The composite rise time ( $T_r$ ) for the three stages is approximately equal to the following:

$$\begin{aligned} T_r &= \left[ (t_1)^2 + (t_2)^2 + (t_3)^2 \right]^{1/2} \\ &= \left[ (1.0 \times 10^{-9} \text{ sec})^2 + (2.4 \times 10^{-9} \text{ sec})^2 + (1.75 \times 10^{-9} \text{ sec})^2 \right]^{1/2} \\ &= < 3.13 \text{ nsec} \end{aligned}$$

which is consistent with the system measurement requirements. The total component or module delay time using the specified intrinsic delays for each element is equal to 5.6 nsec. Coaxial cable lengths will be kept as short as possible to keep the system delays in this path to a minimum.

The desired gate width for switching the QD410 Charge Digitizers is  $\approx 2.5$  nsec. This appears to be quite feasible using appropriate MECL III and 10,000 logic. However, since the QD410's have a linear range of 0 to 25 mA and a sensitivity of 0.25 pico coulombs/channel (250 pico coulombs maximum), the full channel range of this device cannot be used since the 25 mA limitation is exceeded at:

$$Q_m = (I_m) (T_w) = (25 \times 10^{-3}) (2.5 \times 10^{-9}) = 62.5 \text{ pico coulombs}$$

where

$$Q_m = \text{maximum charge}$$

$$I_m = 25 \text{ mA}$$

$$T_w = 2.5 \text{ nsec}$$

which equals one fourth of the dynamic range of the device and sets the maximum channel at

$$\text{Maximum channel} = \frac{Q_m}{Q_s} = \frac{62.5 \times 10^{-12}}{.25 \times 10^{-12}} = 250$$

where

$$Q_s = \text{charge sensitivity}$$

which indicates that if the input range is appropriately set using proper ND attenuation filters, the signal returns from the surface and the bottom can be contained within this unit.

### 3.1.3 Fluorosensing Data Acquisition

The basic block diagram in Fig. 29 shows the data acquisition signal path to be used in the fluorosensing mode. The multipliers chosen for this application are the RCA 8644 and the C70042K. Both tubes are 1.9 cm (0.75 in.) in diameter and have identical physical dimensions which should minimize packaging problems. The 8644 was chosen to satisfy the requirements for the first seventeen spectrometer channels because it exhibits the highest quantum efficiency over this range (3500 to 5412 Å). The C70042K was found to be the best choice to cover the range from 5400 Å to 8000 Å. Both tubes have a typical current amplification of  $8 \times 10^4$  which falls short of the gain necessary to satisfy the input charge requirements of the charge digitizers. It will therefore be necessary to provide additional gain to more closely match the input signal to the QD 410's. A Lecroy Model 161 amplifier appears to be the best choice; with a gain of ten and fast response ( $< 2.0$  nsec) and minimum intrinsic delay (1.5 nsec). The signal path for a single channel of fluorosensing electronics is shown in Fig. 30 along with the rise times and propagation delays. The composite of the rise times shown ( $T_f$ ) are approximately:

$$\begin{aligned} T_f &= \left[ (t_1)^2 + (t_2)^2 + (t_3)^2 \right]^{1/2} \\ &= \left[ (1.0 \times 10^{-9} \text{ sec})^2 + (2.0 \times 10^{-9} \text{ sec})^2 + (1.75 \times 10^{-9} \text{ sec})^2 \right]^{1/2} \\ &= 2.84 \text{ nsec} \end{aligned}$$

which is consistent with the measurement requirements. The total component or module delay from the input to the charge digitizer is equal to 3.5 nsec and cable lengths will be kept as short as practical to minimize the overall system delay.

The gate widths for the charge digitizers have been sized to range between 10 and 50 nsec. An incremental (10-20-30-40-50) gate approach, using appropriate MECL logic, will be used to implement this requirement. In this mode, the full dynamic channel range can be used since:



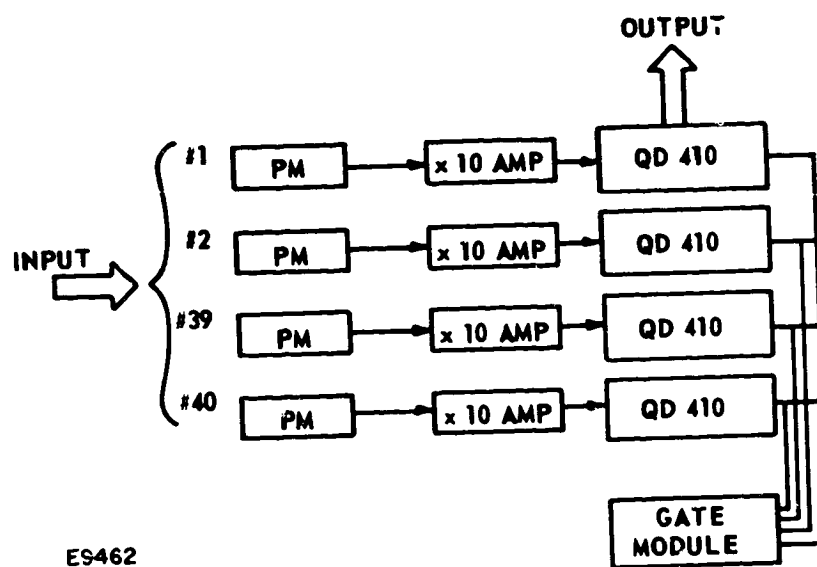


Fig. 29 Data Acquisition Block Diagram - Fluorosensing

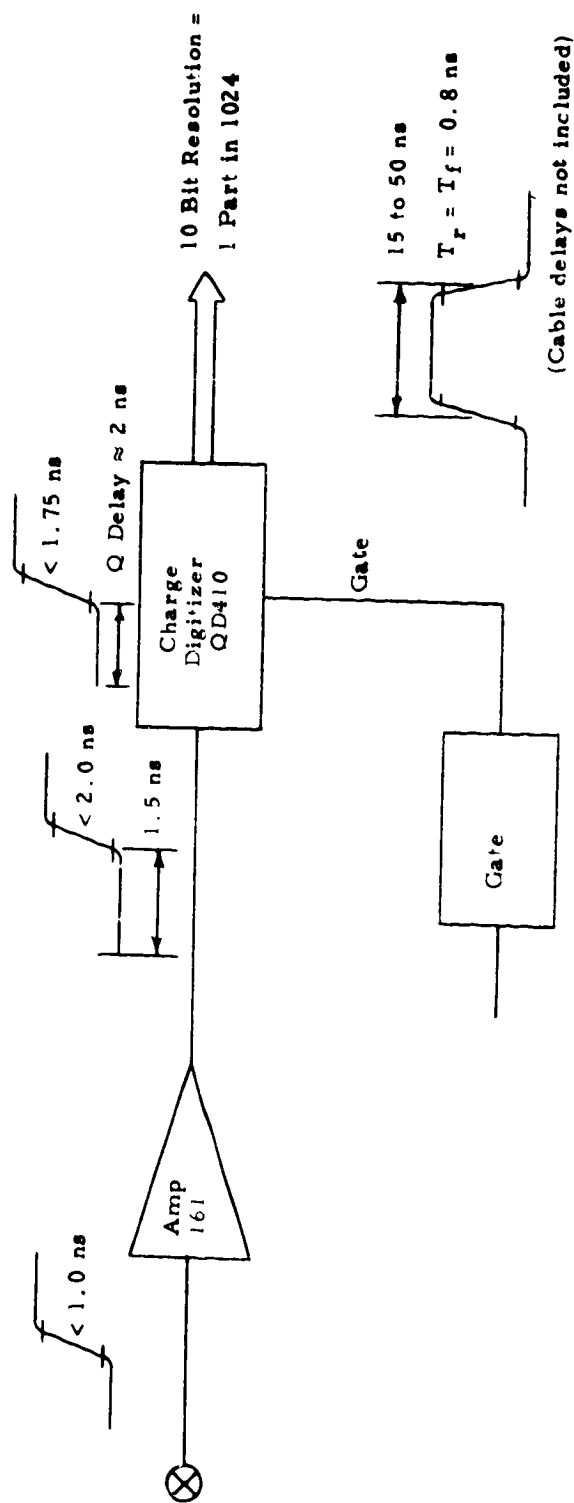


Fig 30 Fluorosensing Signal Path Tolerances

$$Q_m = (I_m)(T_w) = (25 \times 10^{-3})(10 \times 10^{-9}) = 250 \text{ pico coulombs}$$

which is the full scale of channel charge accepted by the QD 410's, indicating that a range of approximately  $10^3$  can be accepted by the charge digitizer in the fluorosensing mode.

#### 3.1.4 Altitude Intervalometer Timing Tolerances

The timing diagram in Fig. 31 shows the rise times, propagation on intrinsic delays and associated tolerances for each of the modules needed to implement the altitude intervalometer. The intrinsic delays associated with the Lecroy 612 buffer amplifier, Lecroy 161L discriminator and Berkley 7030 pulse delay generator add to give the total specified delay of 85.5 nsec (this value will be measured and documented on the system). The delay generator, including initial and delayed pulse and time digitizer have specified tolerances of  $\pm 0.1$  nsec  $\pm 0.5$  nsec and  $\pm 0.2$  nsec for the intervals required in this application. The RSS value of the three tolerances = 0.55 nsec. If approximately another 0.5 nsec is allowed for jitter or amplifier rise time variations, the results indicate that the total tolerance can be held to  $\pm 1.0$  nsec.

Representative intervals for three of the typical altitudes required for this application are also shown. At the worst case altitude of 609 m, the predominant tolerance is that associated with the Berkley 7030 delay pulse generator ( $\pm 0.5$  nsec). At higher altitudes, the delay jitter tolerance (0.01% of delay interval) would start to predominate and reduce the aircraft altitude measurement accuracy accordingly.

#### 3.1.5 CAMAC Interconnecting Diagram

The details of the Control and Data Acquisition Subsystem are summarized on the CAMAC interconnecting diagram, Fig. 32. The figure shows hardware model numbers and general electronic module interconnections. Modules not designated will be comprised of high speed MECL integrated circuits. With the exception of the bathymetry and fluorosensing photo-multipliers, all equipment will be mounted in two CAMAC crates.

### 3.2 Signal Processing Subsystem

#### 3.2.1 I/O Controller

##### A. CPU Time and Memory Allocation

In Table XIII is presented time estimates for each of the functions or operations required to be performed within the CPU. As a result of

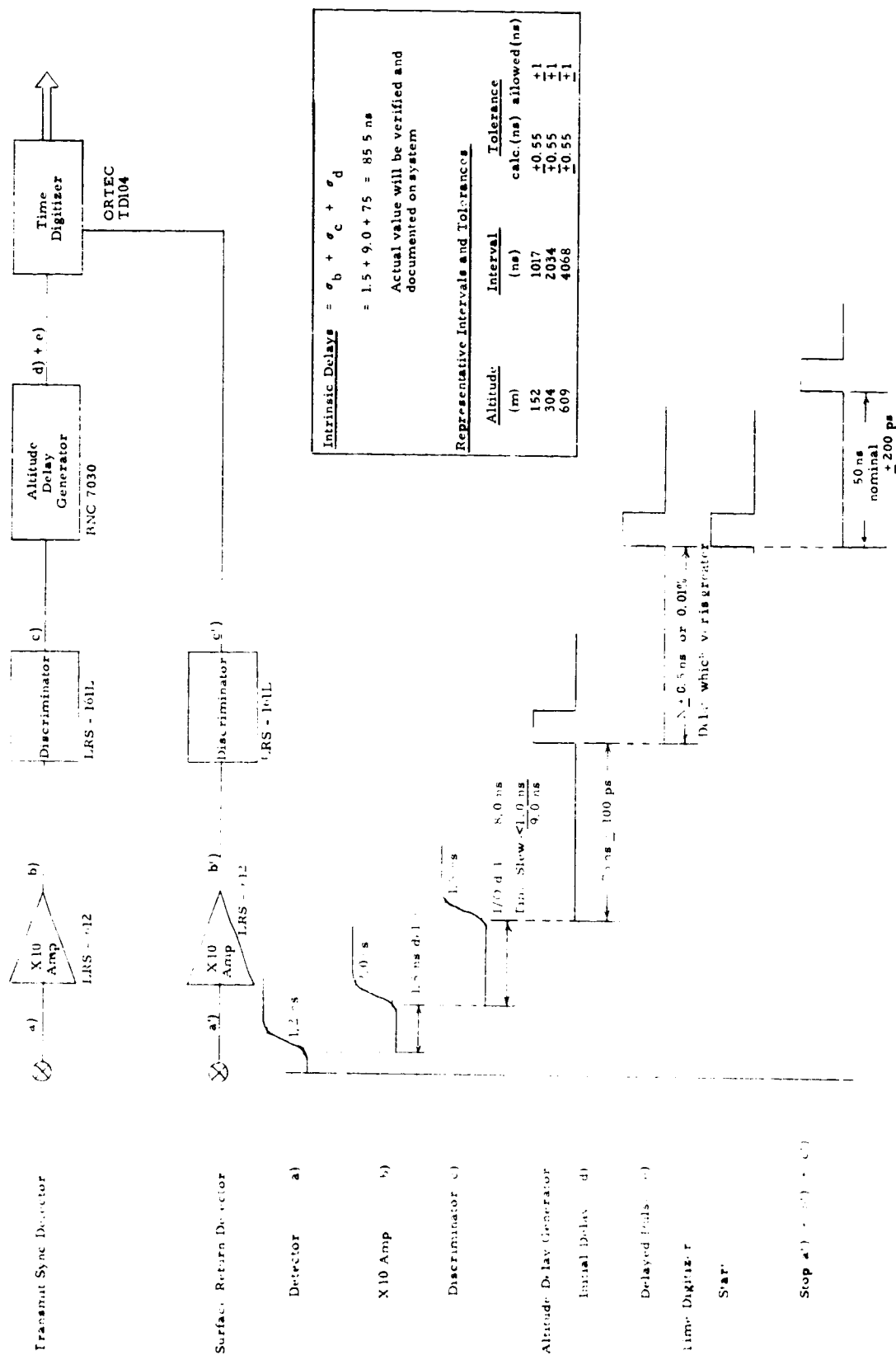
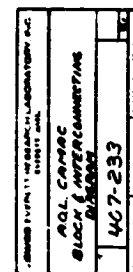


Fig. 31 Altitude Intervalometer Timing Tolerances



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TABLE XIII  
CPU TIME ALLOCATION ESTIMATES\*

<u>Description</u>	<u># of Bytes - Cycles</u>	<u>PTUs/Byte</u>	<u>Freq/Sec.</u>
Data Input	33,554	$6 \times 10^{-6}$	.201
Disc Transfers	33,554	$1.3 \times 10^{-6}$	.044
Interval Calc.	25 x 400	$10 \times 10^{-6}$	.100
Status Update	50 x 8	$2 \times 10^{-6}$	~.001
Graphic Update	11,000	$10 \times 10^{-6}$	.110
Application Exec.	10 x 400	$10 \times 10^{-6}$	.080
Operating Sys. Exec.	5,000	$10 \times 10^{-6}$	.100
Housekeeping	10 x 17	$10 \times 10^{-6}$	<u>~.002</u>
			0.638 sec/sec
			= ~64% dedication

\*During Data Taking

these estimates, it can be seen that the CPU is approximately 64% dedicated, which allows a conservative margin should data rates or the number of channels for housekeeping increase in the future.

A preliminary CPU memory allocation estimate is shown in Fig. 33. As indicated, 28 k would be required to satisfy present needs and approximately 4 k of space will be available to allow for some growth. Should greater expansion be required for future experiments this can be accomplished modularly in increments of 8 k.

#### B. Controller

The I/O controller chosen to satisfy the application requirements of the system is a Hewlett Packard 2125A discomputer containing the following features and options:

##### a) Features:

- 1) 128 standard instructions (including floating point and EAU)
- 2) 178 user accessible micro-orders
- 3) Power fail and recovery
- 4) Memory protect
- 5) Dual channel port control (direct memory access)
- 6) Disc loader ROM (bootstrap loader)
- 7) Software Real Time Executive RTE II system is a disc-based, foreground-background, time and event scheduled real-time multiprogramming system. It is supported by multilingual program development software including Fortran IV, Algol, machine language compilers, debuggers and assemblers. Drivers are provided for controlling and passing information using the RTE II operating system for all major processing peripherals and I/O channels.
- 8) File and memory management

##### b) Options:

- 1) 32 k semiconductor memory (to satisfy resident application, graphic I/O and blank common or buffer area for momentarily storing raw data and housekeeping).

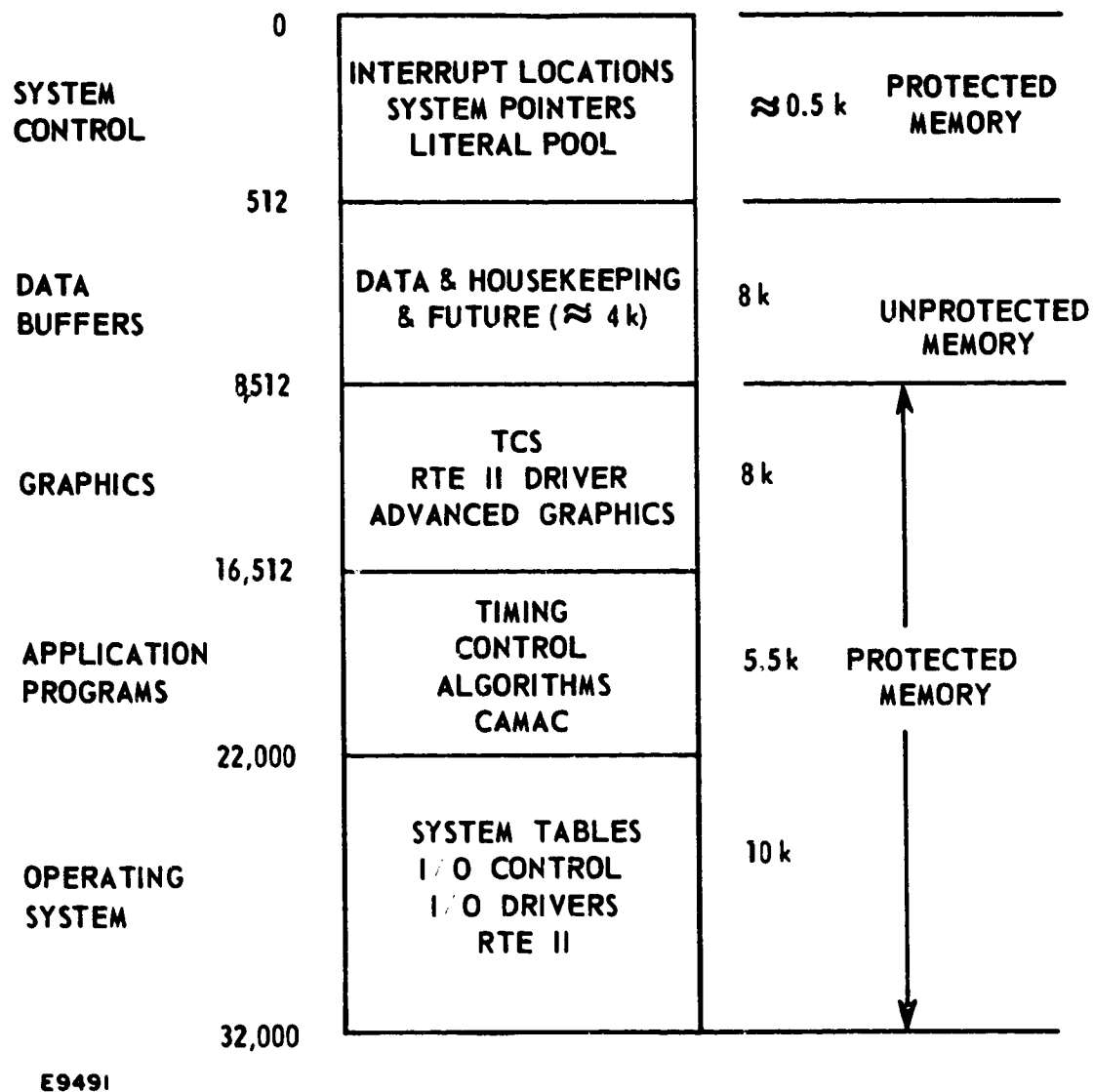


Fig. 33 CPU Memory Allocation Map



### C. Disc Unit

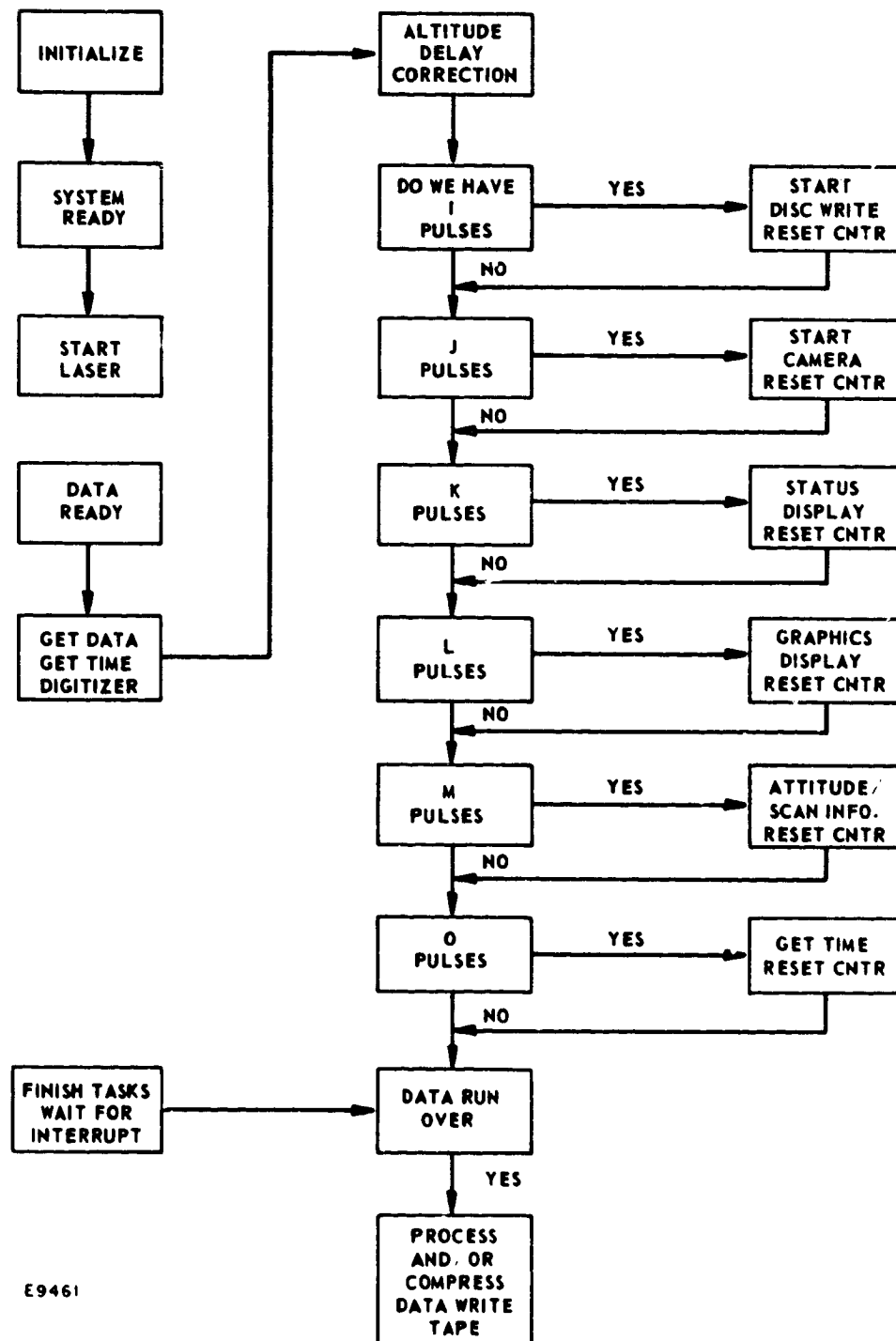
The Hewlett Packard 12962 A cartridge disc subsystem has the performance and capacity necessary to satisfy the application requirements for the system. The manufacturer has indicated that with proper shock mounting and preferred orientation, this unit will perform properly in an aircraft environment. Disc storage capacity is 14,745,600 bytes on one removable disc containing approximately 10 megabytes on two sides and one fixed disc containing 5 megabytes on a single surface. Voice coil head positioning provides exceptionally fast seek times; average track to track in 5 msec, average random in 25 msec, maximum stroke in 45 msec. The data transfer rate of the unit is 937.5 k bytes/sec. (Calculations on disc sizing requirements are presented in para. 3.2.2.3 of this section of the report.)

### D. Programs

The system programs and subroutines will be structured using the general concept shown in Fig. 34. An initialization routine will take appropriate inputs from the keyboard, select the major mode to be run, draw the grid, label graphics display, and ensure that all peripherals are in the proper mode and in a ready state. The major portion of this routine will be written in Fortran.

Once initialization has been accomplished, the system will be placed in a ready state, waiting for a system trigger or start command (input via keyboard). The data ready signal will be accepted from the CAMAC interface via the I/O controller priority interrupt system. The CAMAC data will then be transferred from the various registers (time digitizer and charge digitizers) to the I/O controller memory. The altitude delay correction algorithm routine will be scheduled on a per pulse basis to account for aircraft and seastate variations. The result of this calculation will update the altitude delay generator. These routines will be written in machine language due to the real time responses required.

The remainder of the routines will be scheduled on the basis of the number of pulses received as shown in Fig. 34. The disc and graphic routines indicated will be generated using a combination of FORTRAN and machine language. The disc routine will be used to dump raw data onto



E9461

Fig. 34 System Software Flowchart

the disc every Ith pulse; "I" to be determined by the most efficient record size for system. The graphic routine will generate a real time display in each mode to give a valid indication of the quality of the data.

The remaining routines shown in the figure will be implemented using a philosophy similar to the major routines outlined. With this approach, all routines can be generated using a modular software concept such that each can be altered or modified easily, if or when the need arises.

### 3.2.2 Displays

#### 3.2.2.1 Status Display

A status display will be designed which will indicate the system mode or operation and status of all major subsystems. A combination of discrete light emitting diodes (LED's), latch circuitry, and control and selection logic will be configured to interface with the I/O controller. System status will be updated once every two seconds and visual information will be transmitted to the display for operator interrogation. Provisions will be included to stop or freeze the display in order to access each major subsystem. A preliminary layout of the status display is shown in Fig. 35.

#### 3.2.2.2 Graphics Display

A Tektronix 4012 computer display terminal fulfills all the major requirements for satisfying the alphanumeric and graphic needs of the AOL system. The alphanumeric mode allows selection of the full ASCII set of 96 upper and lower case printing characters or the 63 character TTY subset. In graphics mode, vector presentations of system data will be presented in response to computer commands. The display is a direct view storage CRT, with a display area 20.3 cm (8 in.) wide by 15.2 cm (6 in.) high. The graphics matrix is set up to provide 1024 X by 780 Y viewable points. The graphics terminal is also supported with an extensive software package to easily interface with the I/O controller and generate graphics using high level language techniques (Fortran IV). High level statements are included for axis generation, scaling and labeling tasks. Using this software package provides an expedient and cost effective means of generating display graphics for all system modes. Typical display presentations are shown in Figs. 36 and 37 for each mode of operation.

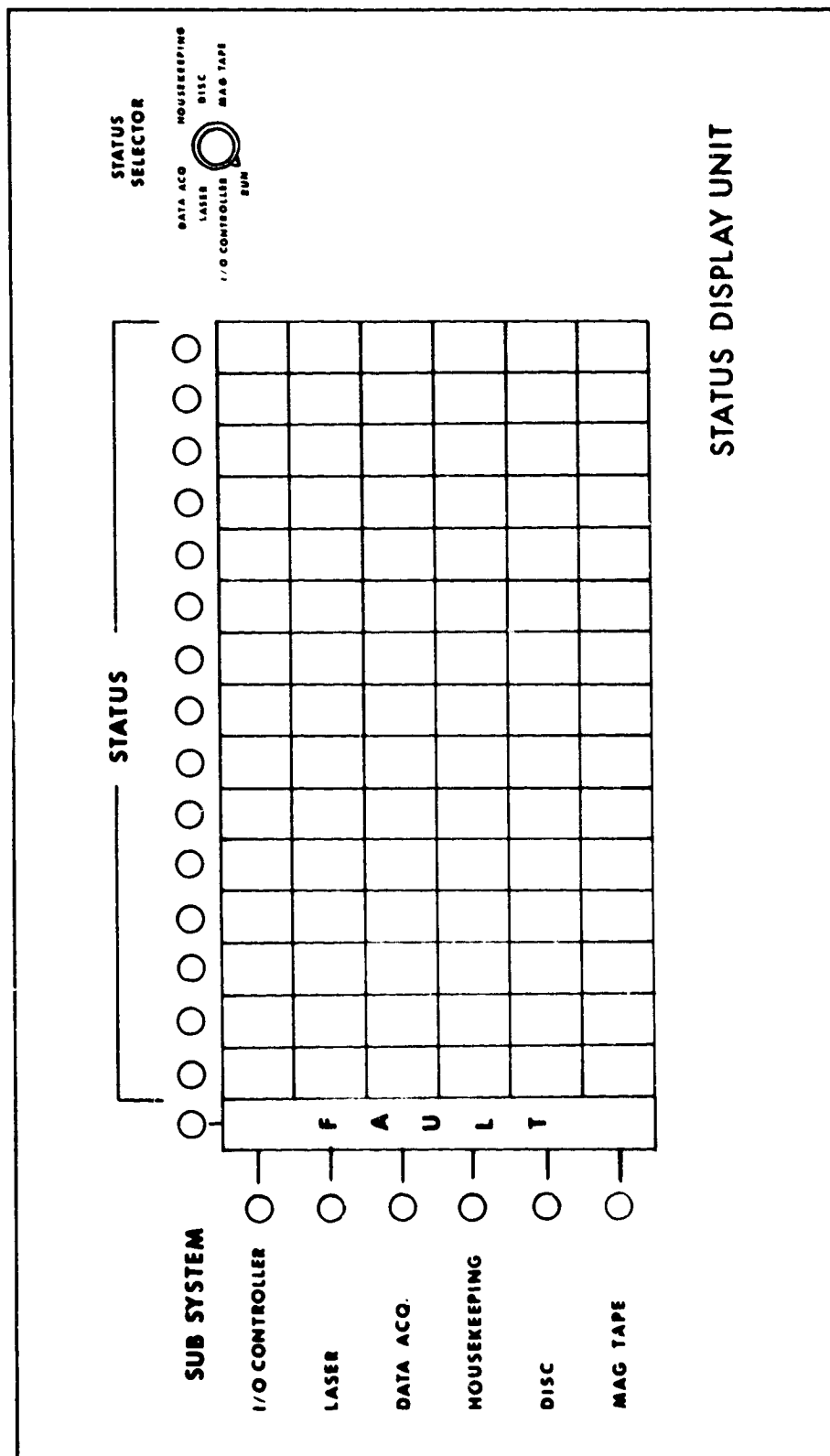
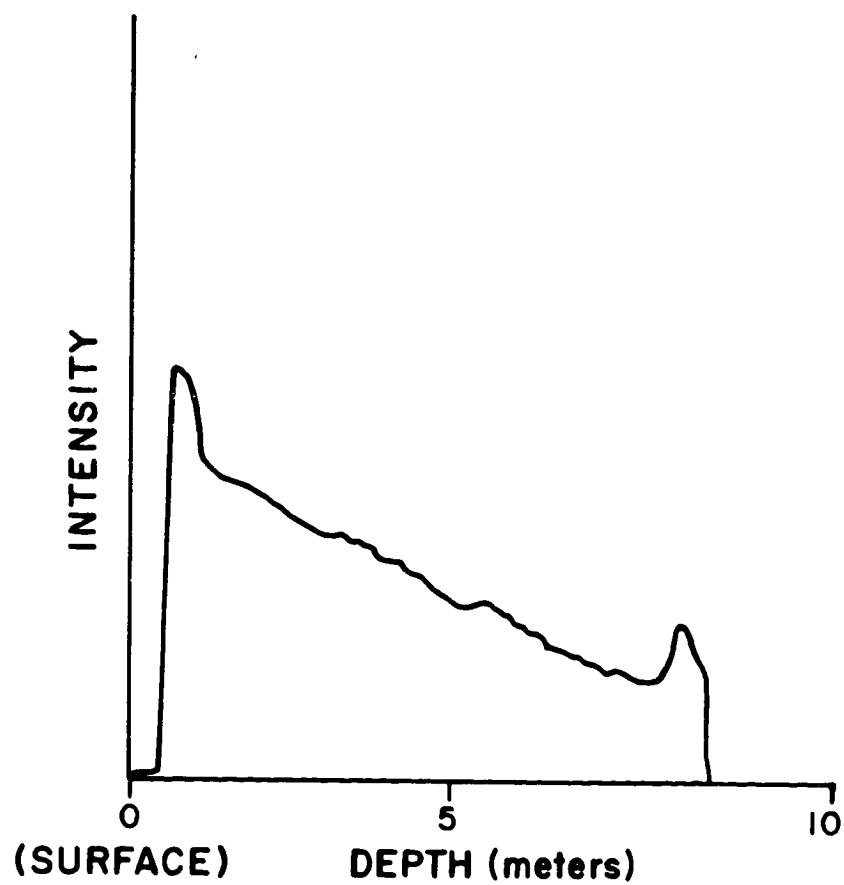


Fig. 35 Preliminary Status Display Layout



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Fig. 36 Typical Bathymetry Display

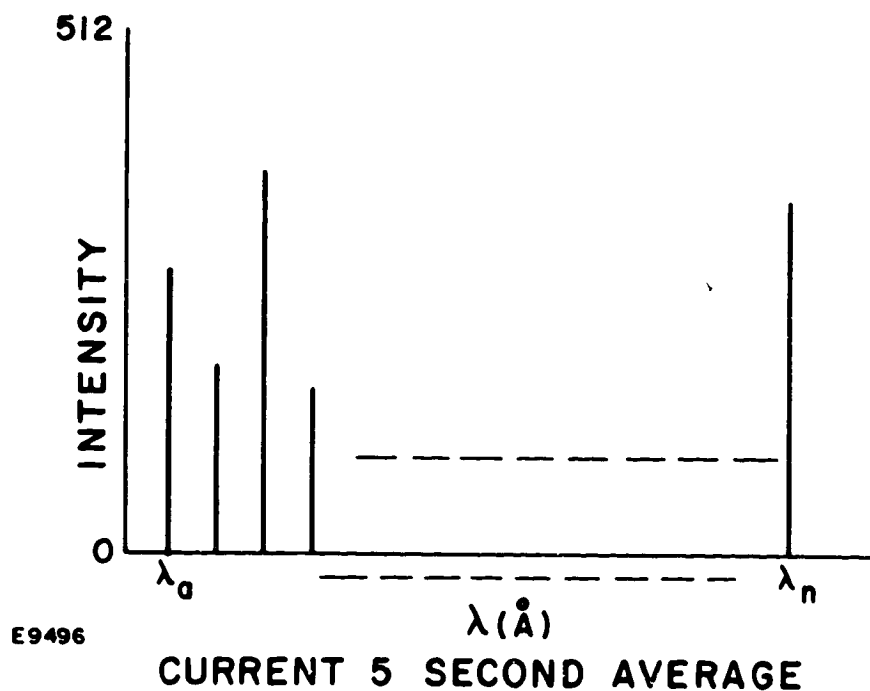
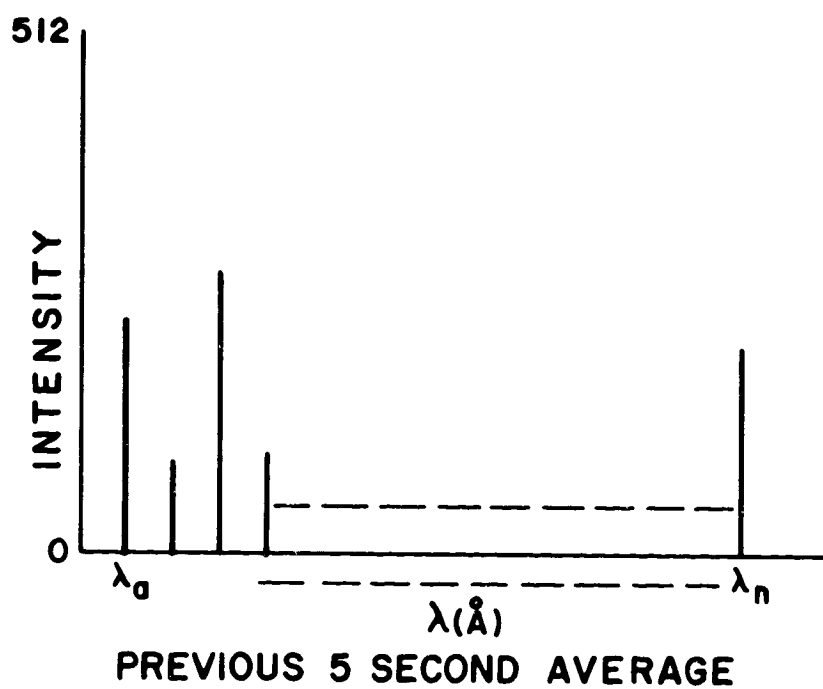


Fig. 37 Typical Fluorosensing Display - Split Screen

### 3.2.2.3 Monitor Oscilloscope

A Tektronix Model 475 oscilloscope was selected for this purpose to provide the following capabilities: 1) to observe the raw (analog) photo-multiplier data and, 2) as a diagnostic tool in tracing various analog and/or digital signal paths. The Model 475 has a 200 MHz at 2 V/cm bandwidth, a 1 nsec/div sweep rate, and an 8 x 10 cm calibrated viewing area and is contained in a 7 x 19 x 18 cm rack-mountable enclosure.

### 3.2.3 Recording

#### A. Recording Rate and Endurance Estimates

Table XIV provides a list of the various system data and house-keeping sources and the anticipated number of bytes/sec required for the worst case (bathymetry) AOL measurement application. In order to size the disc requirements, the following assessment was made:

If there are

33,554 bytes/sec

then the number of bytes to be placed on the disc during a one minute data taking interval would be:

$$33,554 \times 60 = 2,013,240 \text{ bytes/min}$$

The maximum endurance on disc if we allow 10 M bytes for data storage would be:

$$\frac{10 \times 10^6}{2,013,240} \approx 5 \text{ min}$$

The disc format is set at 512 bytes per block (256 words), and since there are 33,554 bytes/sec it is clear that:

$$\frac{33,554 \text{ bytes/sec}}{512 \text{ bytes/block}} = 65.54 \text{ blocks/sec}$$

are required to be transferred to the disc.

To provide a reasonable duty cycle for disc transfers, an alternate (ping-pong) buffer storage of 2048 words each could be used to service:

1) incoming data, and 2) disc writing requirements via the dual port controller channels. This would yield a transfer rate of one transfer every

$$\frac{4096 \text{ bytes}}{33,554 \text{ bytes/sec}} = 0.1221 \text{ sec}$$

This results in satisfying the data requirements with a modest amount of storage (4096 words) and keeps the input and disc writing overhead required

TABLE XIV  
SYSTEM DIGITAL RECORDING REQUIREMENTS

<u>Item</u>	<u>Description</u>	<u># of Words</u>	<u># of Bytes</u>	<u>Rate (Samples/Sec)</u>	<u>Bytes/ Sec</u>
1	40 Data Channels	40	2	400	32, 000
2	RTOD	1	6	40	240
3	Housekeeping				
	A/D	10	2	10	200
	Digital	1	2	20	40
4	Attitude				
	Latitude	1	4	1	4
	Longitude	1	4	1	4
	Ground Speed	1	2	20	40
	Drift Angle	1	4	10	40
	Pitch	1	2	10	20
	Roll	1	2	10	20
5	Intervalometer	1	2	400	800
6	Scanner	1	2	40	80
7	Status	1	2	1	2
8	Identification (Est.)	32	2	1	<u>64</u>
Total:					33, 554

Note: The recording estimate is presented for the worst case mode of data collection, e. g., for bathymetry.



by the CPU relatively low. Since the operational scenario as presently conceived, is envisioned to require no more than a total of one minute of data taking/pass and at least two minutes between passes, a reasonable recording approach would be to transfer the raw data from the disc to CPU and edit, format, and record the information between passes.

For recording, assuming a worst case (no data editing between disc and recording), the following tape conditions would result:

Assuming 4:1 - data: IRG - packing factor

$$2,013,240 \text{ bytes} \times \frac{5}{4} = 2,516,550 \text{ bytes}$$

$$\begin{aligned} \text{The transport specification} &= 800 \text{ bytes/in} \\ &= 36,000 \text{ bytes/sec} \end{aligned}$$

$$\begin{aligned} \text{Recording time per pass} &= \frac{2,516,550 \text{ bytes}}{36,000 \text{ bytes/sec}} \\ &= 69.904 \text{ sec} \end{aligned}$$

Using a total of:

$$\begin{aligned} 45 \text{ in/sec} \times 69,904 &= 3,145.68 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}} \\ &= 262.1 \text{ ft/pass} \end{aligned}$$

Using a 1,097 m (3600 ft) roll of magnetic tape, this results in a tape endurance of 13.73 min of data per roll.

#### B. Magnetic Tape Recording

A Hewlett Packard Model 12970A wide track, 800 BPI, digital magnetic tape recorder has been chosen to satisfy the requirements of this application. Some of the important features of this unit are:

- a) Fast data transfer - up to 36 k bits/sec
- b) Dynamic braking
- c) Accommodates up to 26.6 cm (10.5 in) reels
- d) The unit is IBM/ANSI compatible
- e) It is software supported and integrated to HP RTE II

#### 3.3 Housekeeping

Housekeeping will be accomplished using a Hewlett Packard 2313B analog digital interface subsystem for converting analog housekeeping signals and a Hewlett Packard 12604B data source interface card for handling bit discrete and encoded housekeeping information.

The Model 2313B analog digital interface subsystem has the following characteristics related to signal processing:

Resolution	12 bits, including sign LSB 5 mV
Full Scale Input	+10.235 V to -10.240 V
Throughput Rate to Buffer	To 45 kHz, max, using DMA
Aperture Time	50 nsec (paced)
No. of Inputs	16 differential

The data source interface card will accept from 5 to 100 V - "1" state signals with transfer rate of up to 1000 readings/sec. The digital housekeeping signals from various subsystems will be accepted by this module and transferred to the I/O controller.

### 3.4 Electrical Interfaces with NASA Equipment

#### 3.4.1 Inertial Navigation System

A Litton Industries Model LTN-51, in its basic configuration, is presently mounted on the NASA C-54 research aircraft. Various outputs of the navigator will be utilized by the AOL computer for computation and information transfer to the recorder. Table XV lists the output specifications for BCD data available from the LTN-51 and Table XVI lists the output specifications for its analog data. The following parameters are required from the LTN-51 to support AOL data processing and reduction: latitude, longitude, ground speed, drift angle, pitch and roll. As indicated, the aircraft present position in terms of latitude and longitude are available once per second as an output in BCD format, to six significant figures and to 0.1 minutes resolution. Ground speed is available 20 times per second in BCD format to four significant figures and one knot resolution. Drift angle is available 10 times per second in BCD format with three significant figures and 0.1 degrees resolution. Pitch and roll information is provided from a three wire synchro with 0.04° resolution and 0.2° accuracy. The synchro output will be connected to a synchro to digital converter, BCD output with  $\pm 4$  minutes accuracy and sampled 10 times per second.

#### 3.4.2 Timing

Timing will be derived from an existing NASA 36 bit time code generator (Astrodata Model 6220 universal time code translator). All data will be appropriately tagged with encoded RTOD as required for correlation purposes.

TABLE XV  
LTN-51 OUTPUT SPECIFICATIONS - BCD DATA

<u>Parameter</u>	<u>Qty</u>	<u>Range</u>	<u>Units</u>	<u>Resolution</u>	<u>Sig* Fig</u>
Distance to go	1	0 to 3999.9 nm	nm	0.1 nm	4
Time to go	1	0 to 399.9 min	minutes	0.1 min	4
Cross-track distance	1	0 to 399.9 min	nm	0.1 nm	4
Desired track	1	0° to 360.0°	degrees	0.1 deg	4
Track angle error	1	0° to 180.0°	degrees	0.1 deg	4
Drift angle	1	0° to 39.9°	degrees	0.1 deg	3
Align status	1	"90" to "0"	N/A	N/A	2
Present-position latitude	1	0 to 90°N 0 to 90°S	degrees/ minutes	0.1 min	6
Present-position longitude	1	0 to 180°E 0 to 180°W	degrees/ minutes	0.1 min	6
Ground speed	1	0 to 2000 kts	knots	1.0 knot	4
Track angle	1	0° to 360.0°	degrees	0.1 deg	4
True Heading	1	0° to 360.0°	degrees	0.1 deg	4
Wind Speed	1	0 to 399 kts	knots	1.0 knot	3
Wind Angle	1	0° to 360.0°	degrees	1.0 deg	3
Waypoint latitude	10	0° to 90°N 0° to 90°S	degrees/ minutes	0.1 min	6
Waypoint longitude	10	0° to 180°E 0° to 180°W	degrees/ minutes	0.1 min	6

\* Number of significant bits does not include sign.

TABLE XVI  
LTN-51 OUTPUT SPECIFICATIONS - ANALOG DATA

Function	Qty	Type Output	Range	Resolution	Accuracy	Index Reference	Positive Dir Sense	Scale Factor	Load Capability	Phase
Pitch 1	1	3-wire synchro ARINC 407 equiv 200 mV/degree	0° to +90° 0° to 15° 15° to 30° 30° to 90°	0.04° 0.04° 0.04°	0.2° 0.5° 1.0°	0° = horizon	nose up	1° = 1°	three 500 ohm CTs	0° to +11°
Pitch 2 & 3	1	3-wire synchro ARINC 407 equiv 200 mV/degree	0° to +90° 0° to 15° 15° to 30° 30° to 90°	0.04° 0.04° 0.04°	0.5° 0.5° 0.5°	0° = horizon	nose up	1° = 1°	three 500 ohm CTs	0° to +11°
Pitch 4	1	2-wire isolation transformer	0° to +90° 0° to 30° 30° to 90°	0.04°	0.5° 1.0°	0° = horizon	nose up	200 mV/°	5k to 10k ohms	0° to +11°
Pitch 5	1	2-wire isolation transformer	0° to +90° 0° to 30° 30° to 90°	0.04°	0.5° 1.0°	0° = horizon	nose up	50 mV/°	10k to 40k ohms	-8° +4° -2°
Pitch 6 (customer option)	1	2-wire isolation transformer derived from Pitch 3	0° to +90° 0° 0° to 90°	0.04°	≤ 40 mV + 3% at 25°C + 8% over -18°C to +70°C temp range	0° = horizon	nose up	11.5V sinθ 10.65V sinθ	5k ± 1% 4k ± 1%	+30° +4° -4.0°
Roll 1	1	3-wire synchro ARINC 407 equiv 200 mV/degree	0° to +180° 0° to 15° 15° to 30° 30° to 180°	0.04° 0.04° 0.04°	0.2° 0.5° 1.0°	0° = horizon	a/c right wing down	1° = 1°	three 500 ohm CTs	0° to +11°
Roll 2 & 3	2	3-wire synchro ARINC 407 equiv	0° to +180° 0° to 75° 15° to 30° 30° to 180°	0.04° 0.04° 0.04°	0.5° 0.5° 1.0°	0° = horizon	a/c right wing down	1° = 1°	three 500 ohm CTs each	0° to +11°
Roll 4	1	2-wire isolation transformer	0° to +90° 0° to 30° 30° to 90°	0.04°	0.5° 1.0°	0° = horizon	a/c right wing down	200 mV/°	5k to 10k ohms	0° to +11°
Roll 5	1	2-wire isolation transformer	0° to +90° 0° to 30° 30° to 90°	0.04°	0.5° 1.0°	0° = horizon	a/c right wing down	50 mV/°	10k to 40k ohms	+8° (+4° -2°)
Roll 6 (customer option)	1	2-wire isolation transformer derived from Roll 3	0° to +180° 0° 0° to 180°	0.04°	≤ 40 mV + 3% at 25°C + 8% over -18°C to +70°C temp range	0° = horizon	a/c right wing down	11.5V sinθ 10.65V sinθ	5k ± 1% 4k ± 1%	+10° +4° +30° +6.5° 04.0°
Platform Heading	1	3-wire synchro ARINC 407 equiv 200 mV/degree	0° to 360°	0.1°	± 0.2°	N/A	nose right	1° = 1°	3 passive 5 ohms CTs	0° to +11°
True Heading	1	3-wire synchro ARINC 407 equiv 200 mV/degree	0° to 360°	0.1°	± 0.4°	0° = true north	nose right	1° = 1°	3 passive 500 ohms CTs	0° to +15°
Actual Track Angle	1	3-wire synchro ARINC 407 equiv 200 mV/degree	0° to 360°	0.1°	± 0.5°	0° = true north	CW from true north	1° = 1°	3 passive 500 ohms CTs	0° to +15°
Track Angle Error	1	3-wire synchro ARINC 407 equiv 200 mV/degree	0° to ± 180°	0.1°	± 0.5°	0° = desired track	track left of desired track (CCW)	1° = 1°	3 passive 500 ohms CTs	0° to +15°
Drift Angle	1	3-wire synchro	0° to ± 19.9°	0.1°	± 0.5°	0° = actual track angle	true heading to the left of track	1° = 1°	3 passive 500 ohms CTs	0° to +15°

Parallel 42 bit (LSB = 1 msec) timing information will be input to the I/O controller on command. In addition, the 36 bit NASA 1 second code will be used to drive and expose timing marks on the ground truth camera film.

#### 3.4.3 Power Control and Distribution

A power control and distribution unit will provide the interface between aircraft power and the input power to the various AOL system units. The unit will contain line circuit breakers and individual unit circuit breakers. Input line filters will be included on the input power busses and where required line filters will be provided on power lines to individual units of the system. In addition the unit will be totally enclosed.

Lamps will indicate power availability from the busses and to the units. A system power on timer will be provided to indicate total operating time for equipment maintenance purposes.

A power control and distribution circuit, atypical of the type to be utilized, is shown in Fig. 38. The 115 V, 60 Hz input power is fed through EMI line filters which remove unwanted transient signals. A circuit breaker and a power switch control the power of each bus. Individual circuit breakers are used for the protection of circuits that distribute power to each subsystem unit. A preliminary layout of the power control and distribution panel is shown in Fig. 39.

#### 3.5 Electronics System Weight and Power Estimates

Weight and power estimates for AOL electronics system modules have been prepared and are listed in Table XVII. The summary shows that the total estimated weight is 437 kg (963 lbs) and that approximately 6.3 kW of 60 Hz, single phase power will be required for the system.

#### 3.6 Preliminary Electronics Rack Layout

The various electronics units have been arranged in a preliminary rack layout, Fig. 40. As can be seen, three racks, 152 cm Hx 48 cm W (60 in. x 19 in.), will accommodate the equipment. One rack has been set aside for the laser electronics and the fast pulse signal processing electronics. This rack also contains room for growth or spillover from the remaining racks. Two racks are required to contain that electronics which should be near the operator including the magnetic tape transport,

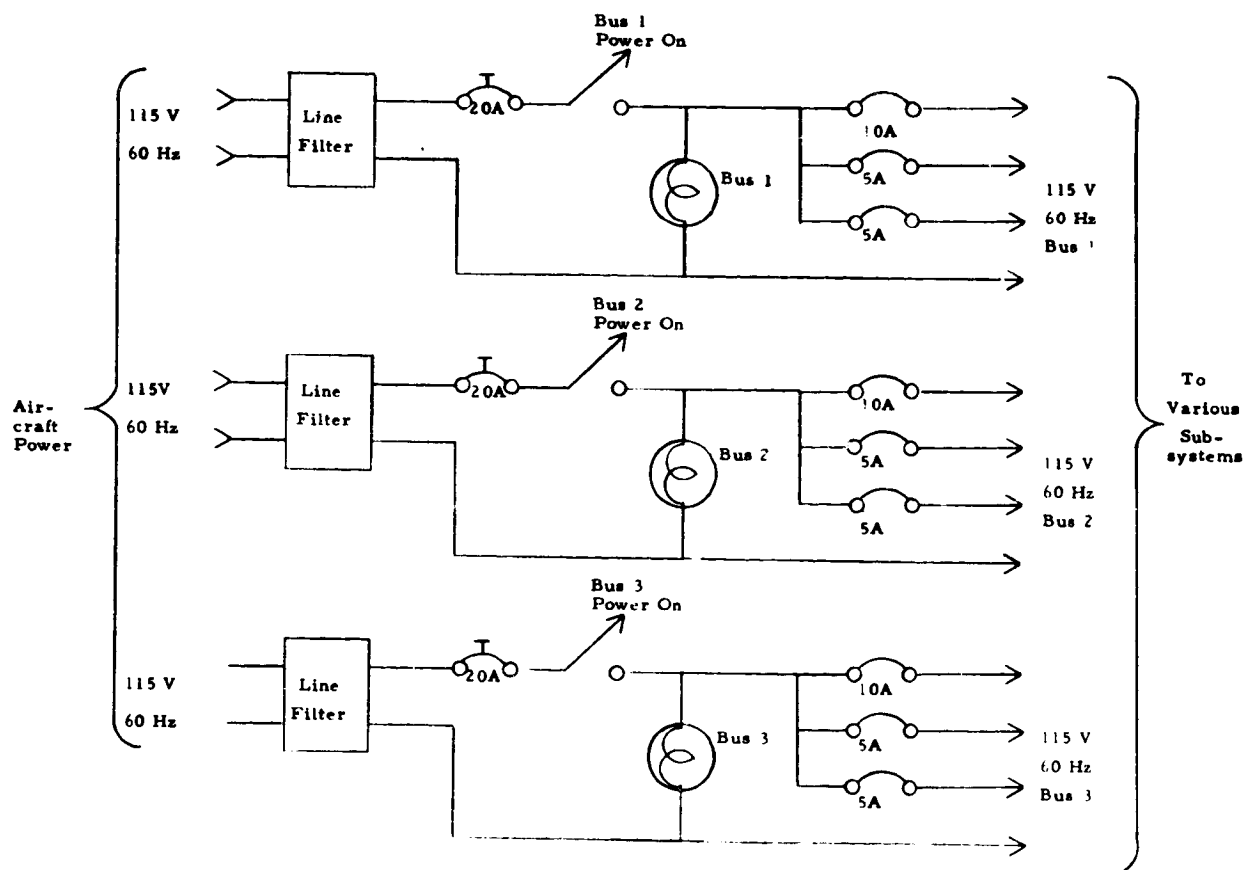


Fig. 38 Typical Power Control and Distribution Circuit

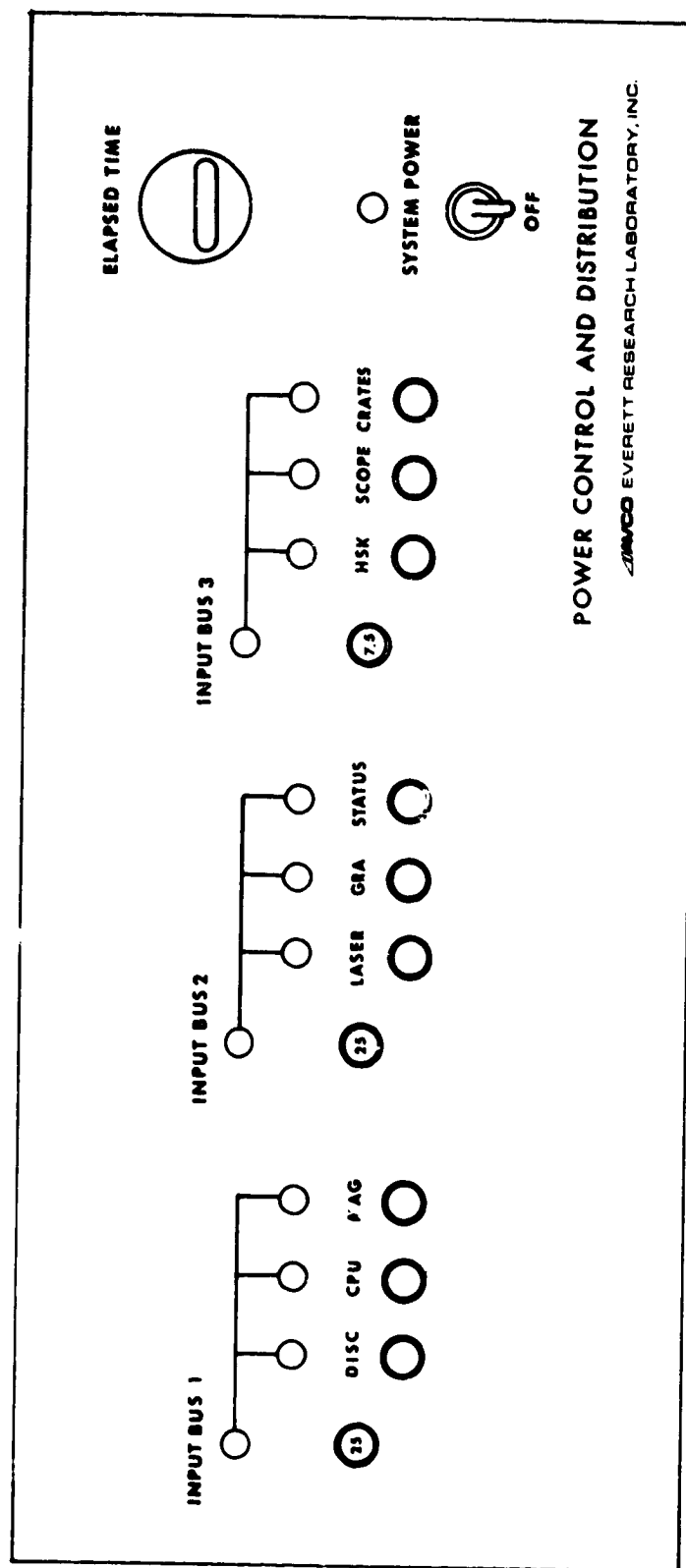
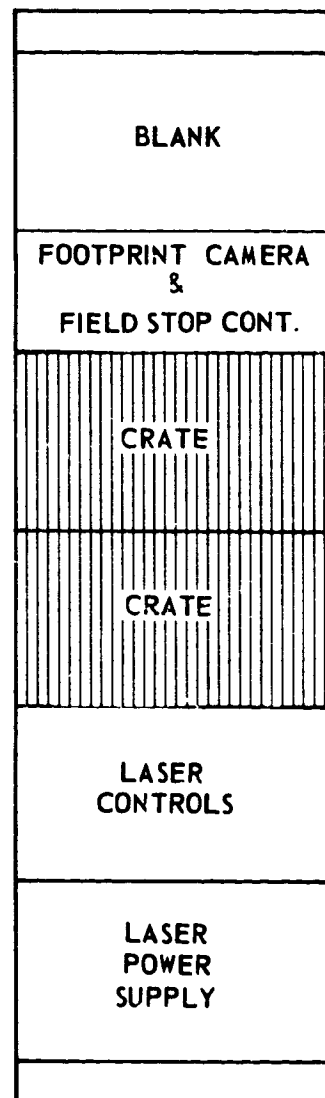
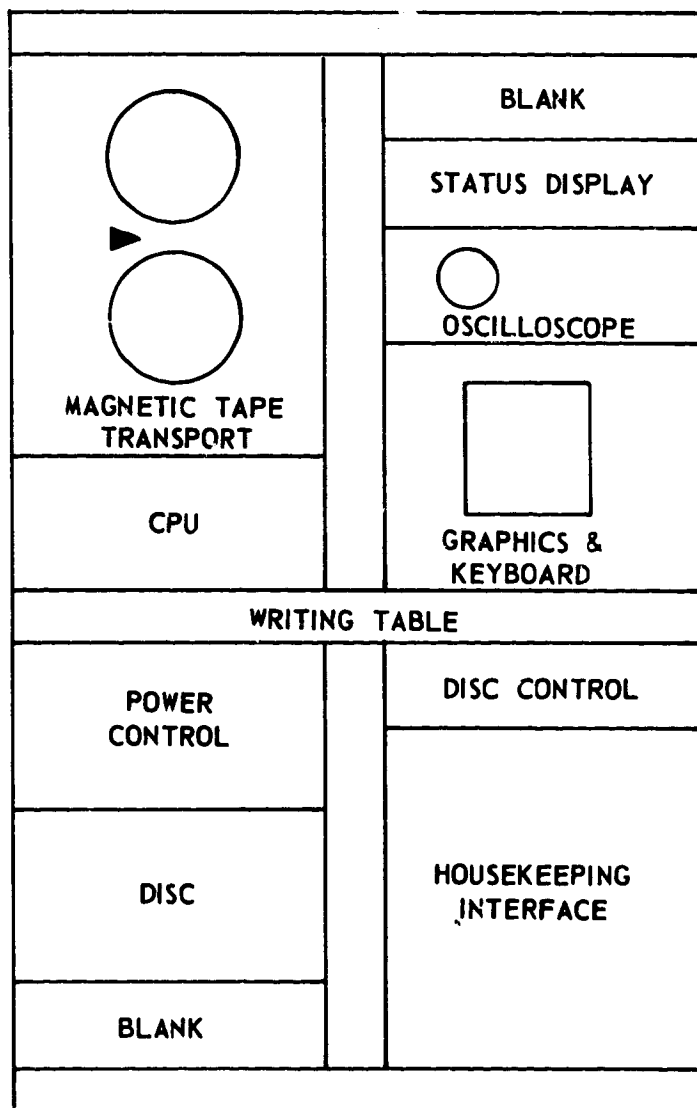


Fig. 39 Preliminary Power Control and Distribution Panel Layout

TABLE XVII  
ESTIMATED ELECTRONICS SYSTEM WEIGHT AND POWER

<u>Unit or Module</u>	<u>Weight (kg)</u>	<u>Power Requirements (Watts)</u>
HV supply 6516A	7	40
HV supply 6522A	19	270
CAMAC crate 1902A	36	400
CAMAC crate 1902A	36	400
CAMAC inteface 2201	9	70
Gate module in CAMAC Crate		100
Control gate & sync. in CAMAC Crate		100
Discomputer 2125A	74	500
CPU M 20	20	520
A/D converter 2315B	30	400
Mag. tape 1297A	63	400
Display term. and Keyboard R4012	41	110
Oscilloscope R475	13	100
Field stop/Footprint camera control	5	100
Status display	7	100
Power control	9	10
C950 laser power & control	<u>68</u>	<u>2640</u>
Total:	437 (963 lbs)	6260





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Fig. 40 Preliminary Electronics Rack Layout

CPU, graphics and keyboard. The units are located at reasonable arms length and the keyboard is at the operator's finger tips. Some unassigned space is available to allow flexibility for unit size changes during AOL detail system design.

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